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Redbooks

Learn the history of IBM® Redbooks®

The International Technical Support Organization (ITSO), best known for its signature IBM Redbooks brand, is one of the most enduring organizations in IBM at 40 years old. It started as the World Trade Systems Center (WTSC) in 1968 and has been publishing the popular technical "how-to" guides known as IBM Redbooks ever since.

The Birth of IBM Redbooks

The WTSC's original function was to distribute documents from the IBM development labs in the U.S. to international locations.

"The country organizations did not have very close ties to the development labs and, therefore, sometimes found it difficult to gain access to key information about products," said Bart Jacob, an ITSO Project Leader. "To help remedy this, we created support centers at key IBM development sites in the U.S."

The WTSC also created technical documents of its own, which became known as IBM Redbooks. The first technical document was published in 1969, but the first official IBM Redbooks document was published in 1973. In the early years of the WTSC, several U.S. centers wrote similar documents but gave them different colored covers. For example, the Raleigh center wrote Greenbooks, and the Dallas center wrote Bluebooks.

Prior to the Internet, the WTSC copied thousands of pages and mailed them every month to the various international divisions of IBM. Because of the expense, delay, and inefficiency of physically mailing these thousands of pages, the WTSC invented Info/Sys, which was a primary vehicle for delivering technical information to larger customers for several years before online methods were available.

The WTSC went through various organizational and title changes—eventually settling on the ITSO—throughout the 1980s and 90s, but one constant was expansion. By 1993, it had 225 employees, including 35 managers and 12 departments around the world. The role of providing direct field support by answering usage questions was removed, and the focus changed almost exclusively to creating IBM Redbooks.

IBM Redbooks Today

IBM Redbooks are developed through an industry unique "residency" process that uses subject matter experts (SMEs) from around the world. IBMers, business partners, and customers spend 4-6 weeks together sharing their experiences and perspectives on the IBM Redbooks topic in one of the ITSO centers. They utilize products as they would be applied in actual client environments and document their findings to create helpful guides "by practitioners, for practitioners".

For IBMers, participating in a residency is a great way to give back to the technical community while enhancing their technical skills, networking with other SMEs, and gaining a global perspective on how clients employ IBM products to build business solutions.

IBM Redbooks cover all of the IBM brands. Over the years, the portfolio of material has grown to cover topics that are not product focused, such as grid computing, automotive solutions, healthcare solutions, and Linux and branch banking.

The ITSO is also looking at ways to tap additional resources in the creation of materials and new material types by embracing Web 2.0 technologies. For instance, the ITSO has been using wiki technologies to allow SMEs with time and travel restrictions to contribute to Redbooks content. In addition, the ITSO has recently launched IBM RedWikis as a way of allowing internal readers to contribute to and enhance existing Redbooks content.

The ITSO, as an organization, is relatively self-sufficient. Aside from a world-class technical staff that drives the projects resulting in Redbooks and other deliverables, they have a support organization including IT staff to help manage their extensive lab environments and servers that host the publications. They also have a staff of editors who help review the content written by technical residents from around the world and ensure a quality and readable document is produced.

IBM Redbooks and other materials produced by the ITSO continue to be the benchmark for quality technical content that enables IBM clients to take full advantage of their investment in IBM products and technologies. It has been for the last 40 years and will likely be for next 40 years and beyond.

Statistics

- Every month over 500,000 IBM Redbooks are downloaded
- Over 100,000 Redpapers are downloaded per month
- 320+ Redbooks materials were published in 2007 - over 400 by year end 2008
- Over 4,800 IBM Redbooks have been published
- Over 1,100 residents participate in the program per year
- In 2007, there were 287 workshops with almost 6,000 students
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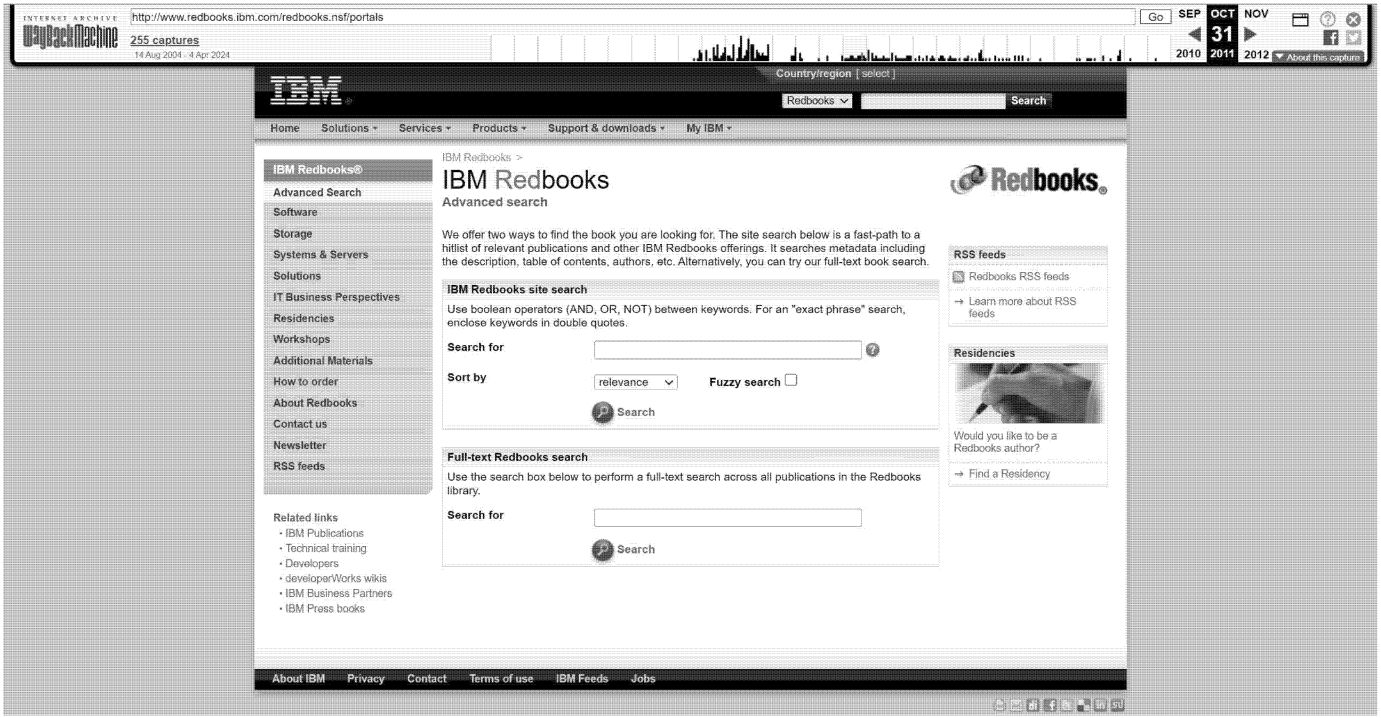
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Abstract

In this IBM® Redbooks® publication, we discuss and describe the positioning, functions, capabilities, and advanced programming techniques for IBM InfoSphere™ Streams (V2), a new paradigm and key component of IBM Big Data platform. Data has traditionally been stored in files or databases, and then analyzed by queries and applications. With stream computing, analysis is performed moment by moment as the data is in motion. In fact, the data might never be stored (perhaps only the analytic results). The ability to analyze data in motion is called real-time analytic processing (RTAP).

IBM InfoSphere Streams takes a fundamentally different approach to Big Data analytics and differentiates itself with its distributed runtime platform, programming model, and tools for developing and debugging analytic applications that have a high volume and variety of data types. Using in-memory techniques and analyzing record by record enables high velocity. Volume, variety and velocity are the key attributes of Big Data. The data streams that are consumable by IBM InfoSphere Streams can originate from sensors, cameras, news feeds, stock tickers, and a variety of other sources, including traditional databases. It provides an execution platform and services for applications that ingest, filter, analyze, and correlate potentially massive volumes of continuous data streams.

This book is intended for professionals that require an understanding of how to process high volumes of streaming data or need information about how to implement systems to satisfy those requirements.

See: http://www.redbooks.ibm.com/abstracts/sg247865.html for the IBM InfoSphere Streams (V1) release.

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This edition applies to Version 2.0.0 of InfoSphere Streams (Product Number 5724-Y95).

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Preface

An information revolution has been underway now for more than 40 years. A key event in that revolution was the development of the relational database, and it changed the world. Now, another technology innovation has started a similar change. IBM® InfoSphere™ Streams is radically transforming the information industry by assembling continuous insights from data in motion, that is, from data that might not have yet been stored. This new technology has been developed to deal with the issues of high volume and velocity data, which we call *Big Data*.

This new approach, coupled with relational databases, enables higher expectations regarding the kinds of applications that can be deployed in the enterprise. In much the same way that technology, such as the assembly line, was the culmination of innovation in the Industrial Revolution, InfoSphere Streams is becoming the "assembler of continuous insight" of the Information Revolution. InfoSphere Streams captures and uses data in motion, or streaming data, by processing it as it passes through enterprise applications. With traditional data processing, you typically run queries against relatively static sources of data, which then provides you with a query result set for your analysis. With stream computing, you execute a process that can be thought of as a continuous query. The results are continuously updated as the sources of data are refreshed, or where extended continuous streams of data flow to the application and are continuously analyzed by static queries that *assemble* the results.

Based on the requirements, the assembled results may be stored for further processing or they may be acted on immediately and not stored. As a result, operations can be scaled out to more servers or cores because each core can focus on its own operation in the overall sequence. Like an assembly line, steps that take longer can be further segmented into sub-steps and processed in parallel. Because the data is processed in an *assembly line* fashion, high throughputs can be achieved, and because the data is processed as it arrives, initial results are available much sooner and the amount of inventory, or enrichment data, that needs to be kept on hand is decreased.

IBM has developed IBM InfoSphere Streams to address the emerging requirement for more timely results coupled with greater volumes and varieties of data. The IBM InfoSphere Streams product is the assembly line for insights of the Information Revolution, complementing the relational databases that began the revolution. What is new in Streams is the higher level of abstraction and the ability to make assembly lines available at a distributed cluster level.

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InfoSphere Streams also includes many elemental building blocks, such as text analytics, data mining, and relational analytics, to make it easier for enterprises to build these assembly lines for business insight. We believe that this approach will become widely used, enable us to meet the coming business challenges, and, as with the manufacturing assembly line, will transform the information industry.

InfoSphere Streams provides an execution platform and services for user-developed queries and applications that ingest, filter, analyze, and correlate potentially massive volumes of continuous streams of data. These queries can be changed over time, without interrupting processing, based on intermediate results or application requirements. Developing applications in this type of environment is significantly different than traditional approaches because of the continuous flow nature of the data.

In this IBM Redbooks® publication, we describe the environment for this type of processing, provide an overview of the architecture of the InfoSphere Streams offering, and discuss how best to develop programming applications to operate in this type of environment. This book is intended for professionals that require an understanding of how to process high volumes of streaming data or need information about how to implement systems to satisfy those requirements.

Imagine the business impact of being able to analyze more data than before and faster than before. What if it suddenly became cost effective to analyze data that was too time sensitive or expensive to analyze before? You could more consistently identify new market opportunities before competitors, and be agile enough more immediately respond to changes in the market.

There is tremendous potential in this type of processing. Begin the evolution in your environment today and start to gain the business advantage.

The team who wrote this book

This book was produced by a team of specialists from around the world working with the International Technical Support Organization, in San Jose, California.

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Kevin Foster is a Big Data Solutions Architect at IBM Silicon Valley Lab. He has worked in the database software area for nearly 30 years. In the first half of his career, Kevin worked as a system integrator building custom applications for the United States Government, Boeing, Xerox, Sprint, American Electric Power, and many others. In 1996, he began the next phase of his career working in a variety of roles in software product development, engineering management, technical marketing, and consulting. His current focus is on partner and customer technical enablement for the IBM InfoSphere Streams product. Kevin has a Bachelor's degree in Mathematics from California State University Stanislaus and a Master's degree in Computer Science from Stanford University.



Andy Frenkiel is a researcher and developer at IBM Research in Yorktown Heights, NY. Since starting with IBM in 1989, he has worked on development environments, communication and performance management systems. As a developer on the IBM InfoSphere Streams product, he served as a team lead for the Streams Studio IDE and is currently working on research topics related to design patterns for stream applications. Andy has a Bachelor's degree in Political Science from Colby College, and a Master's degree in Computer Science from Columbia University.

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Bugra Gedik is currently a research staff member at the IBM T. J. Watson Research Center. His research interests are in distributed data management systems, with a particular focus on runtime and compiler design for stream processing. Bugra has served as the chief architect for the IBM InfoSphere Streams product, and is the co-inventor of the SPL and the SPADE stream processing languages. He is the recipient of the IEEE ICDCS 2003, IEEE DSN 2011, and ACM DEBS 2011 best paper awards. Bugra has served as the PC chair for the ACM DEBS 2009 and IEEE CollaborateCom 2007 conferences. He has published over 50 peer-reviewed articles in the areas of distributed computing, data management, and programming languages, and is an IBM master inventor. Bugra received his Ph.D. from Georgia Institute of Technology and his Bachelor of Science degree from Bilkent University.



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Mike Spicer is a Senior Technical Staff Member with IBM Software Group and the Chief Architect for InfoSphere Streams. He is an expert in high performance stream processing systems with nearly 20 years experience and deep contributions to multiple stream related projects. Mike has been an architect and leader on the InfoSphere Streams development team over the last 3 years focusing on the Streams run time. Before joining the Streams team, he was the architect for IBM DB2® Data Stream Edition, and a lead engineer for the IBM Informix® Real-Time Loader. Mike was also a technical lead for the first IBM WebSphere® Front Office for Financial Markets (WFO) product.



Brian Williams is an Executive IT Architect with IBM Software Services Federal (ISSF), in Bethesda, MD. He has over 27 years experience with expertise in enterprise information management, information security, and relational database design and development. Most recently, he has been designing, implementing, and managing stream processing applications using IBM InfoSphere Streams. In addition, he has developed and taught training courses, workshops, and conference labs for InfoSphere Streams. Brian has a Master's degree in Computer Science from Johns Hopkins University.

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1

Introduction

In this chapter, we give you some background about an exciting analytic paradigm called stream computing. We introduce you to the concepts of streaming data and stream computing from the business landscape and informational environment perspectives, and the emergence of real-time analytic processing (RTAP). We then build on this fundamental information to show how IBM has been actively involved in this extreme shift in the process of decision making. The result of years of research into how to meet this challenge is IBM InfoSphere Streams (Streams). To help position this shift, we give you some history about the birth of Streams and how it is designed to provide an optimal platform for developing and deploying key applications to use streaming data in the decisions you need to make and the actions you need to take for the health of your business, and even the quality of your life.

Another of the objectives in this chapter is to provide insight into the following key questions and concepts:

- So what exactly is streaming data?
- What sort of things can be learned from it to improve the fabric of our lives and the functions of our businesses?
- How can developing streams-based applications enable you to become more proactive in the decision making process?
- How does IBM InfoSphere Streams enable you to harness the power of the plethora of information available from traditional and non-traditional sources of data that are moving all around us?

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1.1 Stream computing

Bob Dylan once sang, "For the times they are a-changing" during the 1960s. Although those words could be true, no matter when they are spoken, they could also be considered an insightful understatement of every aspect of our present lives. We live in an age where the functions of communication that were once completely the purview of land lines and home computers are now primarily handled by intelligent cellular phones, where digital imaging has replaced bulky X-ray films, and the popularity of MP3 players and eBooks are changing the dynamics of something as familiar as the local library.

For years, self-professed information evangelists have taken every opportunity to expound on the explosive increase in the amount of available data and the challenge to glean key useful information from the deluge in time to take action. Actually, we have heard these proclamations so often we have become somewhat desensitized to the true impact of such a statement. At a time when this rate of increase is surpassing everyone's projections, many of us still feel the challenge of being able to do something with this tsunami of information to make it relevant to our jobs. Unfortunately, we rarely can. The flood of data is pertinent to all aspects of our lives. We cannot treat all that information as so much background noise any longer. It is time to be more than just aware that all that information is there. We need to integrate it into our businesses, our governments, our educational processes, and our lives. We need to use all of this information to make things happen, not just document and review what has happened.

This desire is not new. We have always wanted to use available information to help us make more informed decisions and take appropriate action in real time. The realization of such a lofty goal as truly real-time analysis has been challenged by many things over the years. There have been limitations in the capabilities of the IT landscape to support the delivery of large volumes of data for analysis in real time, such as processing power, available computing memory, network communication bandwidth, and storage performance. Though some of these constraints still exist, there have been significant strides in minimizing or alleviating some or all of them. One of the biggest challenges to presenting data in real time is not directly related to the capabilities of the data center. One of the main challenges has been the ability to acquire the actual information in a way that makes it available to the analysis process and tools in time to take appropriate action.

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Even today, typical analytical processes and tools are limited to using stored, and usually structured, data. To accommodate this requirement, data acquisition has historically required several time-consuming steps, such as collection through data entry or optical scanning, cleansing, transformation, enrichment and finally loading this data into an appropriate data store. The time it takes for these steps to complete results in a delay before the data is available to be analyzed and used to drive any actionable decisions. Often this delay is enough that any action taken from the analysis is more reactive than proactive in nature.

If there have been challenges to acquiring information in real time, we can only expect the situation to get worse. Our world is becoming more and more instrumented. Because of this phenomenon, traditionally unintelligent devices are now a source of intelligent information. Tiny processors, many with more processing power than the desktop computers of years ago, are being infused in the everyday objects of our lives. Everything from the packages of products you buy, to the appliances in our homes, to the cars we drive now have the capability to provide us with information we could use to make more informed decisions. An example of this situation is shown in Figure 1-1.



Figure 1-1 Information is available from formerly inanimate sources

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Along with the proliferation of instrumentation in everyday products and processes, we are experiencing a surge in interconnectivity as well. Not only is the actual data available right from the sources, but those sources are also interconnected in such a way that we can acquire that data as it is being generated. The acquisition of data is no longer limited to the realm of passive observation and manual recording. The information produced and communicated by this massive wave of instrumentation and interconnectivity makes it possible to capture what is actually happening at the time it happens. Data can be acquired at the source and made available for analysis in the time it takes a machine to *talk* to another machine. Where we once assumed, estimated, and predicted, we now have the ability to know.

These advances in availability and functionality are the driving force in the unprecedented, veritable explosion in the amount of data available for analysis. Are we really ready to use this information? Even with the recent improvements in Information technology, the predicted steady increase in the amount of traditional stored data available was a considerable challenge to realizing true real-time analytics. The world is now able to generate inconceivable amounts of data. This unexpected increase in volume is likely to still outstrip the potential gains we have made in technology, unless we begin to change the way we approach analysis. Just to get that amount of data stored for analysis could prove to be an insurmountable task.

Imagine: In just the next few years, IP traffic is expected to total more than half a zettabyte. (That is a trillion gigabytes, or a one followed by 21 zeroes!).

A further challenge is new sources of data generation. The nature of information today is different than information in the past. Because of the profusion of sensors, microphones, cameras, and medical and image scanners in our lives, the data generated from these instruments is the largest segment of all information available, and about 80% of this information is unstructured. One advantage of this shift is that these non-traditional data sources are often available while they are enroute from their source to their final destination for storage, which means that they are basically available the moment they happen (before they are stored).

Let us consider data feeds from local or global news agencies or stock markets. Throughout their active hours of operation, these data feeds are updated and communicated as events happen. Most of us have at least one of the addresses (URLs) for these live data feeds bookmarked on our browser. We are confident that every time we access this address we will be able to review current data. Conversely, we probably do not have any idea where the historic information goes to finally be stored. More importantly, there may be no need to know where it is stored because we are able to analyze the data before it comes to rest.

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This data that is continuously flowing across interconnected communication channels is considered streaming data or *data in motion*.

To be able to automate and incorporate streaming data into our decision-making process, we need to use a new paradigm in programming called *stream computing*. Stream computing is the response to the shift in paradigm to harness the awesome potential of data in motion. In traditional computing, we access relatively static information to answer our evolving and dynamic analytic questions. With stream computing, you can deploy a static application that will continuously apply that analysis to an ever changing stream of data. As you look at Figure 1-2, think of the difference between doing research for a report on a current event from the printed material in a library verses the online news feeds.

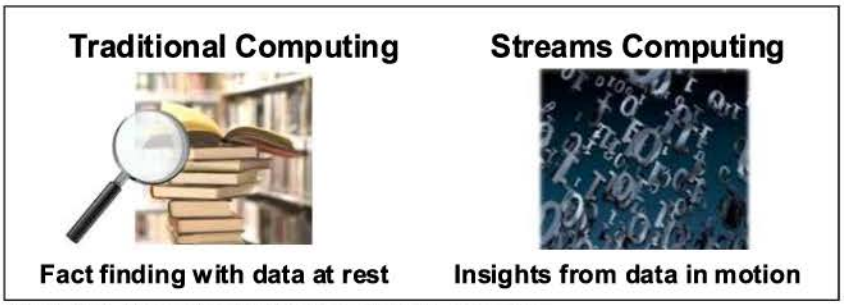


Figure 1-2 Comparing traditional and stream computing

To help you better understand this concept, consider for the moment that you are standing on the bank of a rapidly flowing river into which you are planning to launch a canoe. You have a wetsuit but are not sure if you need to bother with wearing it. You first need to determine how cold the water is to decide whether or not you should put on the wetsuit before getting into the canoe. There is certainly no chance of capturing all of the water and holding it while you determine the average temperature of the full *set* of the water. In addition, you want to leave your canoe while you go to retrieve a newspaper that might have a listing of the local water temperatures. Neither of those options are practical. A simpler option is to stand on the edge of the creek and put your hand or foot into the water to decide whether it was warm enough to forego the wetsuit. In fact, you could also insert a thermometer for a more accurate reading, but that level of accuracy is probably not necessary for this scenario. The water's journey was not interrupted by our need to analyze the information; on the contrary, someone else could be testing those same waters farther downstream for their own informational needs. Much like its watery counterpart in this example, streaming data can be accessed from its edges during its travels without deterring further use downstream or stopping its flow to its final repository.

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Looking at the different programming approaches to analysis, you can see correlations to the river, although historically you have been able to capture all of the information prior to analysis. In traditional computing, you could produce a report, dashboard, or graph showing information from a data warehouse for all sales for the eastern region by store. You could take notice of particular items of interest or concern in your high level analysis and drill down into the underlying details to understand the situation more clearly. The data warehouse supplying information to these reports and queries is probably being loaded on a set schedule, for example, weekly, daily, or even hourly, and not being modified much after the data is committed. So the data is growing over time, but historical data is mostly static. If you run reports and queries today, tomorrow, or a month from now on the same parameters, the results will basically be the same. Conversely, the analysis in this example is evolving and changing from a summary to details. You could, and surely would, take action based on this analysis. For example, you could use it to project replenishment and merchandising needs, but because the analyst must wait until the data is loaded to use, their ability to take those actions in real time is limited. With some analyses and actions, this is a perfectly acceptable model, for example, making plans to update the production process or design a new line based on the success of another line. With stream computing, you can focus on an analysis that results in immediate action. You could deploy an analytic application that will continuously check the ever-changing inventory information that is based on the feeds from the cash registers and the inventory control system and send an alert to the stock room to replenish item(s) more quickly before loading the data.

1.1.1 Business landscape

As previously stated, the potential for data acquisition for analysis is taking place in real time than ever before. Still, most of our decisions, either as business leaders or even as individuals, are made based on information that is historic in nature or limited in scope. Even though most decision makers believe that more current data leads to better decisions, stored data has been the only source of data readily available for analysis. This situation has driven expectations about how the analytic process and the tools that support analysis should work. Businesses historically have to wait until after the actual data has been committed to storage before they can run any analysis. This analysis is then limited to using historical, and usually structured, data to predict the best actions for the future. By being able to acquire actual data in real time, businesses hope to be able to analyze and take action in real time, but they need new products and tools designed to do so.

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Figure 1-3 shows the results of a 2011 IBM study of 3,018 CIOs worldwide. The source of this data is the IBM Institute for Business Value Global CIO Study 2011. The survey found that there are four CIO mandates: Leverage, Expand, Transform, and Pioneer. Nearly one-quarter of the CIOs IBM had a conversation with support organizations that operate with a Transform mandate. Organizations with this mandate see IT primarily as a provider of industry-specific solutions to change the business.

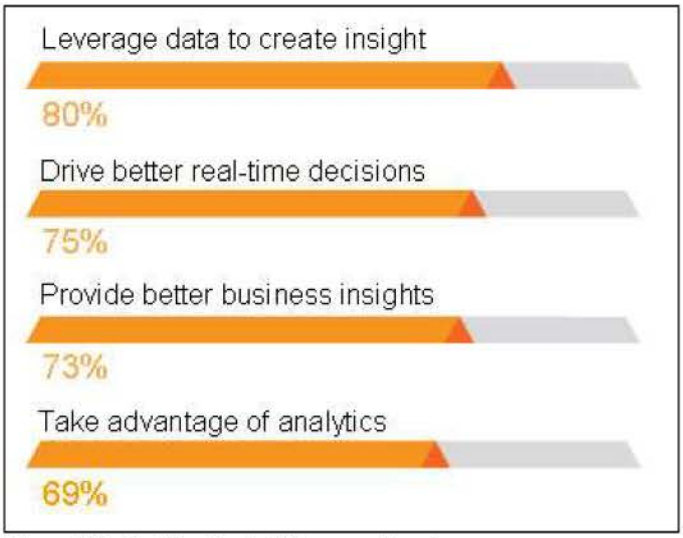


Figure 1-3 Enabling the intelligence enterprise

Beyond the delivery of basic IT services and business process improvements, Transform mandate CIOs are helping their public and private sector organizations fundamentally rethink the way they understand and interact with customers and partners. One key to extending the enterprise's reach is the use of *Big Data*, that is, the vast volumes captured and analyzed, such as data from sensors, RFID tags or real-time, web-based transactions that can be analyzed to drive better, real-time decisions. Big Data, what to do with it, and how to use it are top issues for Transform mandate CIOs.

Why is it that businesses continue to feel an urgency to seek an effective use of analytics? Because before you can determine an effective use strategy, the definition of what it takes to be effective changes. The rapid shift in the complexion of the data causes companies, governments, and even individuals to continually find themselves trying to determine how best to use the new data landscape.

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An excess of good data may sound like a good problem to have, but it means that with enterprise data projected to double every 18 months, it will be hard to keep up. And, with 80% of data growth driven by unstructured and non-traditional data sources, such as email, text, VoIP, and video, it is difficult to even know for which types of data to plan. With the fast pace of today's business environment, industry leaders are constantly being called upon to make innovative decisions in real time to gain a competitive edge, or to simply remain competitive.

The time is certainly near (if not already now) when these images and streaming data will be far more prevalent than their historic structured counterparts. Businesses are challenged by not only the volume and velocity of available data, but also by the ability to interpret the broad range of sources.

Note: A city the size of London could have tens of thousands of security cameras. Roads are often equipped with thousands of sensors for an area as limited as one bridge. Medical diagnostic equipment that creates digitized medical images make up, or will soon make up, almost a third of all the data in the world. Most if not all of these devices are connected to the World Wide Web, where they continually produce data.

The list of sources of available data for analysis just keeps growing. The increased reach of instrumentation brings with it the availability of a volume of data that businesses could never have dreamed would exist. We have smart appliances that can keep smart meters aware of energy usage in small increments for all appliances, which allows the utility company to make capacity adjustments at any level, even within a single home. Even something as basic as a tractor can capture and transmit soil condition, temperature, and water content and directly relay that information to a specific location to be used to monitor and manage water usage for irrigation systems, while simultaneously alerting the local dealership of the fact that the machine needs service. From the potential of smart grids, smart rail, smart sewers, and smart buildings, we can see significant shifts in the way decisions are made in the fabric of our lives.

Simultaneously, as individuals, we are becoming increasingly aware of the value of real-time information, whether to just feel more connected in a society where being in the same physical locality is not always possible between family members and friends, or as a forum to have our opinions heard. The rise in popularity of the social networks indicates that there is also a considerable personal value to real-time information. In this forum, millions of people (and therefore customers, students, patients, and citizens) are voicing their opinion about everything from good and bad experiences they have had with products or companies to their support for current issues and trends.

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Businesses that can analyze what is being said and align themselves with the popular desires will be a powerful force.

In some situations, businesses have tried to build applications to provide functionality beyond traditional analytics tools to use non-traditional or high volume information. Unfortunately, many of these businesses find that their in-house built applications struggle to scale well enough to keep up with the rapidly growing data throughput rates. The reality is that even as the old obstacles to real-time analytics are removed, business leaders are still finding themselves limited in their ability to make truly, real-time decisions. Unless they embrace a new analytical paradigm, the dynamic growth in data volumes will result in increasing the time needed to process data, potentially leading to missed opportunities and lowering, or losing, competitive advantage.

Businesses are keenly aware that knowing how to effectively use all known sources of data in a way that allows future sources to be incorporated smoothly can be the deciding factor that serves to fuel competitive, economic, and environmental advantages in real time. Those companies and individuals that find themselves positioned to be able to use data in motion will certainly find themselves with a clear competitive edge. The time it takes to commit the data to persistent storage can be a critical limitation in highly competitive marketplaces. More and more, we see that the effective key decisions need to come from the insights available from both traditional and non-traditional sources.

1.1.2 Information environment

You can already see that the changes in the business landscape are beginning to blur the lines between the information needs of business and the needs of the individual. Data that was once only generated, collected, analyzed, enriched, and stored in corporate data centers is now transmitted by some of the most innocuous devices. Data that was once only attainable by using the power provided by a business's information environment can now be accessed by devices as personal as intelligent cellular phones and personal computer tablets. With greater availability of data comes the potential for a new breed of analyst to enrich the information content. Thanks to the increases in instrumentation and interconnectivity, these new analysts and their new content can now be heard worldwide in mere seconds. The lines that historically have delineated the information environment into its use by industries, business, government, or individuals are becoming all but invisible. Not only is the world becoming more instrumented and interconnected, but the entire planet is becoming more intelligent, or at least has that potential.

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We are in the dawn of the IBM Smarter Planet™ era in information evolution. As you can see in Figure 1-4, the Smarter Planet era builds from earlier styles of computing, and is being driven by the rapid rise in the level of sophisticated computing technology being delivered into hands of the real world.

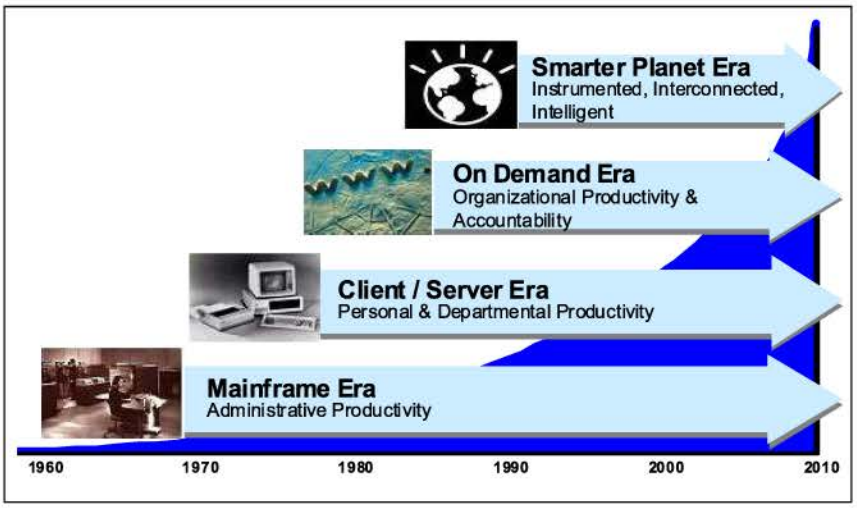


Figure 1-4 Eras of information technology evolution

The need for an automated information environment began in the mid 1960s with the Mainframe Era. A wonderful environment for automating the back office functions, it is still widely in use today. Because all businesses have back offices, the information environment of the Mainframe Era became prolific in all businesses and all industries. Not designed to do things such as plant floor manufacturing, departmental computing, or personal computing, this environment and the data it creates and stores are solely designed for and used by the specific enterprise. The purposes of the applications in this environment are to conduct the day-to-day business. The data it generates is only truly used by the processes of those day-to-day operations, such as billing, inventory control, accounting, and sales analysis.

The awareness of the value of analysis came from the departmental units within the business. The information environment of the Mainframe Era was well suited for creating and storing data, but not as well suited to analyzing that information to make improvements in the way to do business. As departmental decision makers were pressed to improve their bottom lines, they found themselves needing an information environment flexible enough to support any question they needed to ask.

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The Client/Server Era was the first information environment fashioned to support the business analyst. Unfortunately, as it rose from departmental demands, it was an information environment isolated from the data needs of the particular departmental unit. Still, it was quick and effective, and like its predecessor, it still exists in organizations today for targeted needs, such as campaign management.

But soon analysis could no longer be isolated to the departmental domain. The On Demand Era was born out of the need to blend (and validate) the departmental analysis to provide insight and recommendations at the enterprise level. The On Demand Era started integrating these islands of automation into an information environment that could serve the analytical needs of the entire enterprise. The rise of the worldwide Internet, with its open, standards-based, and widely available access, provided a framework to share departmental information within the business and the foundation for sharing information throughout the world at a pace we could barely imagine.

The growth of the environments to support information has been relatively steady over the years and gradually growing. Still, the sources of data and the results of analysis were primarily the property of industry, government, and academic science. These enterprise data centers controlled the information because only they had the computing power to acquire and analyze it. As such, they reviewed and verified information before communicating it to the rest of the world. But with computing power prevalent outside of the walls of industry, we must re-think what a computer really is and who might be performing analysis on the data.

Consider: There were 4.6 billion mobile phone subscribers in February 2010, and there will be 1.3 billion Radio Frequency Identification (RFID) tags produced globally in the next year. Sensors are being embedded across entire ecosystems, such as supply chains, health care networks, electric grids, cities, and even natural systems such as rivers. These sensors and phones can all be considered computers that have the ability to generate and communicate data.

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In the past, the information available on the Internet was only generated and communicated by those large data centers. Now it is estimated that not only will there likely be over 2 billion people connected to the Internet, but there will also be as many as a trillion objects connected as well. This Internet of things, show in Figure 1-5, shows some examples of how computers are moving out of the data centers and into our everyday world.

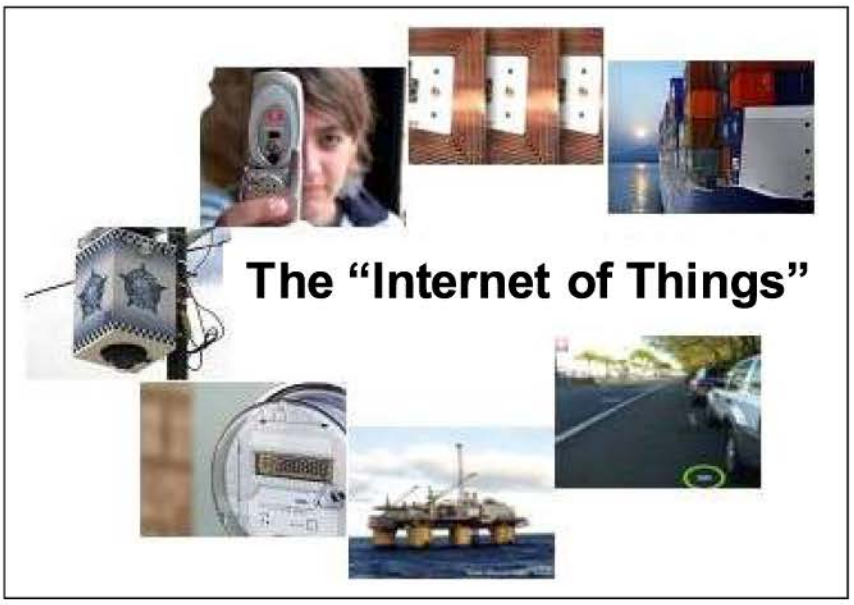


Figure 1-5 Computers are moving out of the data center into the world

The proliferation of these sensors and devices, embedded in everything from smart grids to rail cars, and even chickens, will help drive as much as a 10 times increase in the amount of data in the world. The ability to tap into that data for a new kind of intelligence can help drive vast improvements in our systems.

Welcome to the Smarter Planet Era. Driven by the surge in instrumentation, interconnectivity and intelligence being infused in all aspects of our lives, this new information environment holds the potential to infuse even complex analysis in the routine aspects of our lives. This new environment will enable situations such as having traffic and security cameras in major cities help alert police and other first responders to the logistics of an incident far faster and more precisely than ever before. The information from sensors in your car could alert your garage-of-choice that your car needs maintenance so they can schedule an appointment for you and prompt you to confirm the appointment through a text message on your cell phone.

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In-home monitors that transmit key health factors could have the capability that allows an elderly relative to continue living in their own home. Automated quality analysis installed on a factory line could identify defects in products before they leave the line to allow operators to take corrective measures.

While having access to data sooner may save lives, lower crime, save energy, and reduce the cost of doing business and therefore products, one of the by-products of the widespread instrumentation is the potential for feeling like we live in a *surveillance society*. Although it is easy for people and businesses to see the value of access to the wide variety of data and smarter systems, it is also easy to see how they may be increasingly uncomfortable having so much information known about them. Individuals and businesses alike find themselves concerned that this essential environment might only be as secure and reliable as the average person's mobile computer or PDA.

Note: You may have read an article a few years ago that reported that the London flat in which George Orwell wrote *1984* has 32 closed-circuit cameras within 200 yards, scanning every move. Those cameras were not put there specifically to spy on that flat; they were installed to scan traffic and provide security for local businesses. Still, they are there and as they are most likely connected to the internet, the irony, and the potential concern, is pretty easy to see.

Along with the sheer mechanics of analyzing the massive volumes of information in real time comes the additional challenge of how to provide security and privacy. The information environment of the Smarter Planet Era gets its reaction speed from accessing data in motion, data outside of the usual framework of data repository authorization and encryption features. The sheer volume of the available data in motion requires a high performance environment for stream computing, but this environment also needs to be able to employ in-stream analysis to determine the credibility of sources and protect the information without adversely compromising the speed. When the information environment uses and allows widespread access to analyze and enrich data in motion, it also takes on some of the responsibility to protect the results of that analysis and enrichment of the data and determine the analysis is based on credible and trusted sources.

The potential of the information environment for this new Smarter Planet Era is great, but so are its challenges. Providing an environment capable of delivering valuable and insightful information for real-time analytics without compromising on quality and security is the standard with which we will measure the success of this era.

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1.1.3 The evolution of analytics

Just as the business landscape and information environments are evolving, the approaches to effective analysis are at the dawn of a major evolution. We might think we are drowning in data, but in fact we now have the ability to turn that data into useful information. Advanced software analytic tools and sophisticated mathematical models can help us identify patterns, correlations of events, and outliers. With these new tools, we can begin to anticipate, forecast, predict, and make changes in our systems with more clarity and confidence than ever before. We stand on the brink of the next generation of intelligence: analysis of insightful and relevant information in real time, which is the real value of a Smarter Planet. The evolution of the analytic process is shown in Figure 1-6.

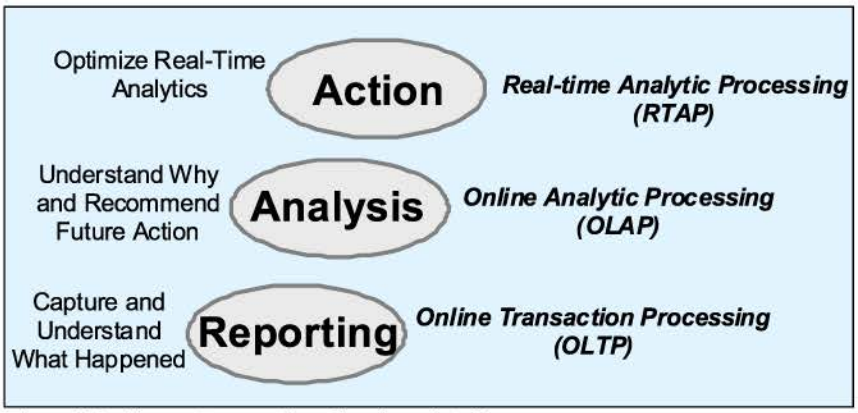


Figure 1-6 The next generation of business intelligence

Hierarchical databases were invented in the 1960s and still serve as the foundation for online transaction processing (OLTP) systems for all forms of business and government driving trillions of transactions today. Consider a bank as an example. It is quite likely that even today in many banks that information is entered into an OLTP system, possibly by employees or by a web application that captures and stores that data in hierarchical databases. This information then appears in daily reports and graphical dashboards to demonstrate the current state of the business and to enable and support appropriate actions. Analytical processing here is limited to capturing and understanding what has happened.

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Relational databases brought with them the concept of data warehousing, which extended the use of databases from OLTP to online analytic processing (OLAP). Using our example of the bank, the transactions captured by the OLTP system were stored over time and made available to the various business analysts in the organization. With OLAP, the analysts could now use the stored data to determine trends in loan defaults, overdrawn accounts, income growth, and so on. By combining and enriching the data with the results of their analysis, they could do even more complex analysis to forecast future economic trends or make recommendations on new investment areas. Additionally, they could mine the data looking for patterns to help them be more proactive in predicting potential future problems in areas such as foreclosures. The business could then analyze the recommendations to decide if they should take action. The core value of OLAP is focused on understanding why things happened to make more informed recommendations.

A key component of both OLTP and OLAP is that the data is stored. Particularly now, some new applications require faster analytics than is possible when you have to wait until the data is retrieved from storage. To meet the needs of these new dynamic applications, you must take advantage of the increase in the availability of data prior to storage, otherwise known as streaming data. This need is driving the next evolution in analytic processing called real-time analytic processing (RTAP). RTAP focuses on taking the proven analytics established in OLAP to the next level. Data in motion and unstructured data may be able to provide actual data where OLAP had to settle for assumptions and hunches. The speed of RTAP allows for the potential of action in place of simply making recommendations.

So, what type of analysis makes sense to do in real time? Key types of RTAP include, but are not limited to, the following analyses:

- Alerting
  - The RTAP application notifies the user(s) that the analysis has identified that a situation (based on a set of rules or process models) has occurred and then optionally provides recommendations and options for the appropriate actions.
  - Alerts are useful in situations where the application should not be automatically modifying the process or automatically taking action. They are also effective in situations where the action to be taken is outside the scope of influence of the RTAP application.

  Some examples are:

  - A market surveillance application that is monitoring a local exchange for suspect activity would notify someone when such a situation occurs.
  - A patient monitoring application would alert a nurse to take a particular action, such as administering additional medicine.

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- Feedback
  - The RTAP application identifies that a situation (based on a set of rules or process models) has occurred and makes appropriate modifications to the processes to prevent further problems or to correct the problems that have already occurred.
  - Feedback analysis is useful, as an example, in manufacturing scenarios where the application has determined that defective items have been produced and takes action to modify components to prevent further defects.

  An example is a manufacturer of plastic containers may run an application that uses the data from sensors of the production line to check the quality of the items throughout the manufacturing cycle. If defective items are sensed, the application generates instructions to the blending devices, for example, to adjust the ingredients to prevent further defects from occurring.
- Detecting failures
  - The RTAP application is designed to notice when a data source does not respond or generate data within a prescribed period of time.
  - Failure detection is useful in determining system failure in remote locations or problems in communication networks.

  Some examples are:
  - An administrator for a critical communications network deploys an application to continuously test that the network is delivering an adequate response time. When the application determines that the speed drops below a certain level, or is not responding at all, it alerts the administrator, wherever they happen to be.
  - An in-home health monitoring application determines that the motion sensors for a particular subscriber have not been activated today and sends an alert to a caregiver to check on the patient to determine why they are not moving around.

When you look at the big picture, you can see that if you consider the improvements that have been made in chip capacity, network protocols, and input / output caching with the advances in instrumentation and interconnectivity and the potential of stream computing, we stand poised and ready to be able to present appropriate information to the decision makers in time for proactive action to be taken. The days of solely basing our decisions on static data are yielding to being able to also use streaming data or *data in motion*.

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1.1.4 Relationship to Big Data

With the growing use of embedded chips in sensors and smart phones, the volume of data generated annually is exploding into the exabyte data size range. With the pervasive deployment of sensors to monitor everything from environmental processes to human interactions, the variety of digital data is rapidly encompassing structured, semi-structured, and unstructured data. Finally, with better and faster networks to carry the data, from wireless to fiber optic, the velocity of data is also exploding. We call data with these characteristics Big Data. Examples include sources such as the Internet, web logs, chats, sensor networks, social media, telecommunications call detail records, biological sensor signals (as examples, EKG and EEG), astronomy, images, audio, medical records, military surveillance, and eCommerce.

With the ability to generate all this valuable data from their systems, businesses and governments are grappling with the problem of analyzing the data for two important purposes: to be able to sense and respond to current events in a timely fashion, and to be able to use predictions from historical learning to guide the response. This situation requires the seamless functioning of data-in-motion (current data) and data-at-rest (historical data) analysis, operating on massive volumes, varieties, and velocities of data. Bringing the seamless processing of current and historical data into operation is a technology challenge faced by many businesses that have access to Big Data.

IBM has introduced a Big Data platform, based on two products: IBM InfoSphere Streams and IBM InfoSphere BigInsights, which are designed to address this class of problems. Both products are built to run on large-scale, distributed systems designed to scale from small to large data volumes, while handling both structured and unstructured data analysis. In this book, we describe various scenarios where data analysis can be performed across the two platforms to address the Big Data challenges.

1.2 IBM InfoSphere Streams

In April of 2009, IBM made available a revolutionary product named IBM InfoSphere Streams (Streams). Streams is a product architected specifically to help clients continuously analyze massive volumes of streaming data at extreme speeds to improve business insight and decision making. Based on ground-breaking work from an IBM Research team working with the U.S. Government, Streams is one of the first products designed specifically for the new business, informational, and analytical needs of the Smarter Planet Era.

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As seen in Figure 1-7, Streams is installed in over 150 sites across six continents. Hundreds of applications have been developed, helping IBM understand more about client requirements for this new type of analysis.

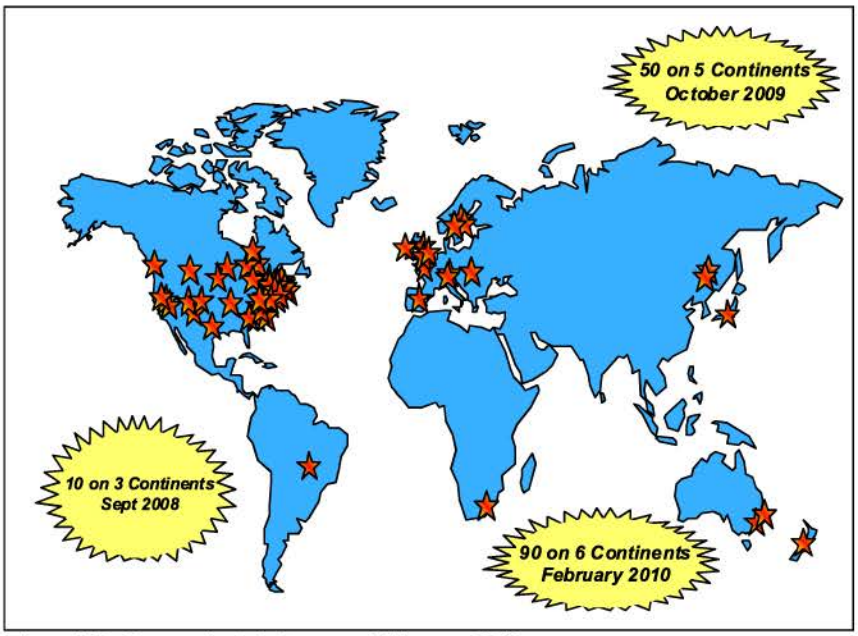


Figure 1-7 Streams installations as of February 2010

Streams is based on nearly a decade of effort by that IBM Research team to extend computing technology to handle advanced analysis of high volumes of data quickly. How important is their research? Consider how it would help crime investigation to be able to analyze the output of any video cameras in the area surrounding the scene of a crime to identify specific faces of any "persons of interest" in the crowd and relay that information to the unit that is responding. Similarly, what a competitive edge it could provide by being to be able to analyze 6 million stock market messages per second and execute trades with an average trade latency of only 25 microseconds (far faster than a hummingbird flaps his wings). Think about how much time, money, and resources could be saved by analyzing test results from chip-manufacturing wafer testers in real time to determine if there are defective chips before they leave the line.

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Note: While at IBM, Dr. Ted Codd invented the relational database. In the defining IBM Research project, it was referred to as System R, which stood for Relational. The relational database is the foundation for data warehousing that launched the highly successful Client/Server and On Demand informational eras. One of the cornerstones of that success was the capability of OLAP products that are still used in critical business processes today.

When the IBM Research division again set its sights of developing something to address the next evolution of analysis (RTAP) for the Smarter Planet evolution, they set their sights on developing a platform with the same level of world changing success, and decided to call their effort System S, which stood for Streams. Like System R, System S was founded on the promise of a revolutionary change to the analytic paradigm. The research of the Exploratory Stream Processing Systems team at T.J. Watson Research Center, which was set on advanced topics in highly-scalable stream-processing applications for the System S project, is the heart and soul of Streams.

Critical intelligence, informed actions, and operational efficiencies that are all available in real time is the promise of Streams. InfoSphere Streams will help us realize the promise of a Smarter Planet.

1.2.1 Overview of Streams

For the purposes of this overview, it is not necessary to understand the specifics, as they will be discussed in more detail in subsequent chapters. The purpose here is only to demonstrate how Streams was designed and architected to focus on the ability to deliver RTAP of exceedingly large volumes of data using a flexible platform positioned to grow with the increasing needs of this dynamic market.

As the amount of data available to enterprises and other organizations dramatically increases, more and more companies are looking to turn this data into actionable information and intelligence in real time. Addressing these requirements requires applications that are able to analyze potentially enormous volumes and varieties of continuous data streams to provide decision makers with critical information almost instantaneously. Streams provides a development platform and runtime environment where you can develop applications that ingest, filter, analyze, and correlate potentially massive volumes of continuous data streams based on defined, proven, and analytical rules that alert you to take appropriate action, all within an appropriate time frame for your organization.

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The Streams product goes further by allowing the applications to be modified dynamically. Although there are other systems that embrace the stream computing paradigm, Streams takes a fundamentally different approach to how it performs continuous processing and therefore differentiates itself from the rest with its distributed runtime platform, programming model, and tools for developing continuously processing applications. The data streams that are consumable by Streams can originate from sensors, cameras, news feeds, stock tickers, or a variety of other sources, including traditional databases. The streams of input sources are defined and can be numeric, text, or non-relational types of information, such as video, audio, sonar, or radar inputs. Analytic operators are specified to perform their actions on the streams. The applications, once created, are deployed to the Streams Runtime.

A simple view of the components of Streams is shown in Figure 1-8:

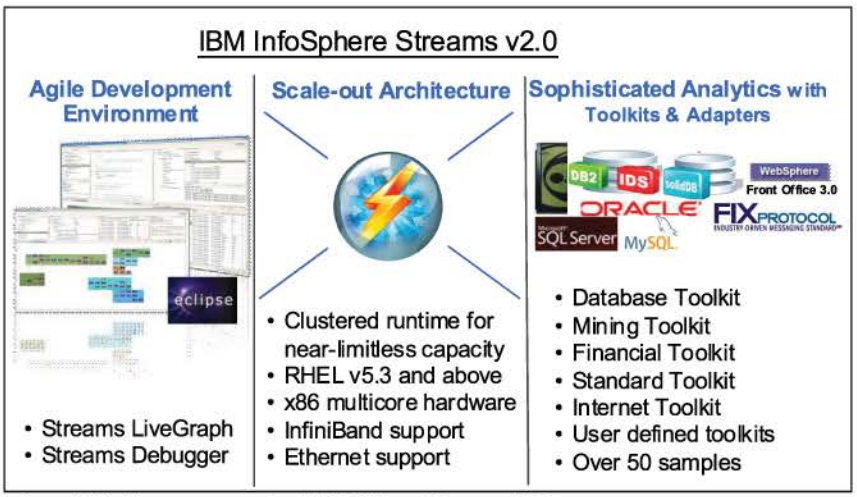


Figure 1-8 The components of InfoSphere Streams V2.0

Applications are developed in the InfoSphere Streams Studio using IBM Streams Processing Language (previously called Streams Processing Application Declarative Engine), which is a declarative language customized for stream computing. Once developed, the applications are deployed to Streams Runtime environment. Streams Live Graph then enables you to monitor performance of the runtime cluster, both from the perspective of individual machines and the communications between them.

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Virtually any device, sensor, or application system can be defined using the language. But there are also predefined source and output adapters that can further simplify application development. As examples, IBM delivers the following adapters:

- TCP/IP, UDP/IP, and files
- IBM WebSphere Front Office, which delivers stock feeds from major exchanges worldwide
- IBM solidDB® includes an in-memory, persistent database using the Solid Accelerator API
- Relational databases, which are supported using industry standard ODBC

Applications, such as the one shown in the application graph in Figure 1-9, almost always have multiple steps.

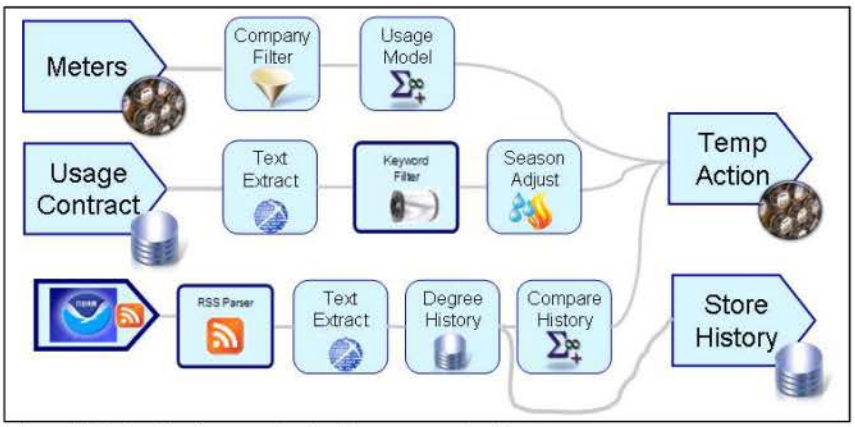


Figure 1-9 Application graph of a Streams application

For example, some utilities have begun paying customers who sign up for a particular usage plan to have their air conditioning units turned off for a short time, allowing the temperature to be changed An application to implement this would collect data from meters, and might apply a filter to only monitor for those customers who have selected this service. Then, a usage model must be applied that has been selected for that company. Up-to-date usage contracts then need to be applied by retrieving them, extracting text, filtering on key words, and the possibly applying a seasonal adjustment. Current weather information can be collected and parsed from the U.S. National Oceanic & Atmospheric Administration (NOAA), which has weather stations across the United States. After parsing for the correct location, text can be extracted and temperature history can be read from a database and compared to historical information.

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Optionally, the latest temperature history could be stored in a warehouse for future use. Finally, the three streams (meter information, usage contract, and current weather comparison to historical weather) can be used to take actions.

Streams delivers an Integrated Development Environment (IDE) based on the Open Source Eclipse project, as shown in Figure 1-10. Developers can specify operators to be used in processing the stream, such as filter, aggregate, merge, transform, or much more complex mathematical functions such as Fast Fourier Transforms. The developer also specifies the data input streams to be used (source operators) and data output streams (sink operators). Some of the source and sink adapters are included within the Streams product and the environment also allows the developer to define custom adapters, including custom analytics or operators written in C++ or Java. Existing analytics can also be called from Streams applications. More details about these functions can be found in the subsequent chapters of this book.

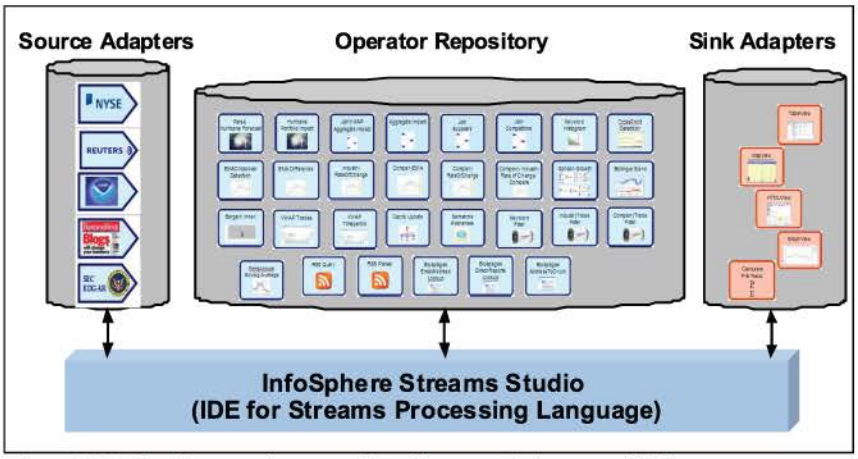


Figure 1-10 The Streams Integrated Development Environment (IDE)

InfoSphere Streams Studio not only helps you develop applications, but includes the powerful Streams Debugger tool. As with many IDEs, you can set breakpoints and stops in your application to facilitate testing and debugging. In addition, the Streams Debugger works with the Streams Runtime and the Streams Live Graph tool so that you can find a break point even after the application has been deployed. You can inspect or inject new data to ensure the application is doing what you want it to do.

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An optimizing compiler translates the application to executable code. The compiler makes many decision to optimize application performance, such as buffer sizes required, which functions should be run on a single machine, and when new execution threads can be initiated. When deployed, the Streams Runtime works with the optimizing compiler to allocate the application across the runtime configuration, similar to the example in Figure 1-11.

The Streams Runtime establishes communications for the streams of data as they are being processed by the application. This task is accomplished by setting up connections to route data into the Streams Runtime, between the various operators, and out of the Streams Runtime cluster. Because the Streams Runtime is all handled in memory across systems within a high speed infrastructure, the overall application experiences extremely low latency.

The Streams Runtime monitors the environment's performance and if it detects poor performance, or hardware failure, the administrator can take corrective actions. For example, the administrator can move an analytic function to another processor in the cluster. The Streams Runtime allows you to add or remove applications without bringing down the cluster. You can also add or remove computer nodes from the cluster while it is running.

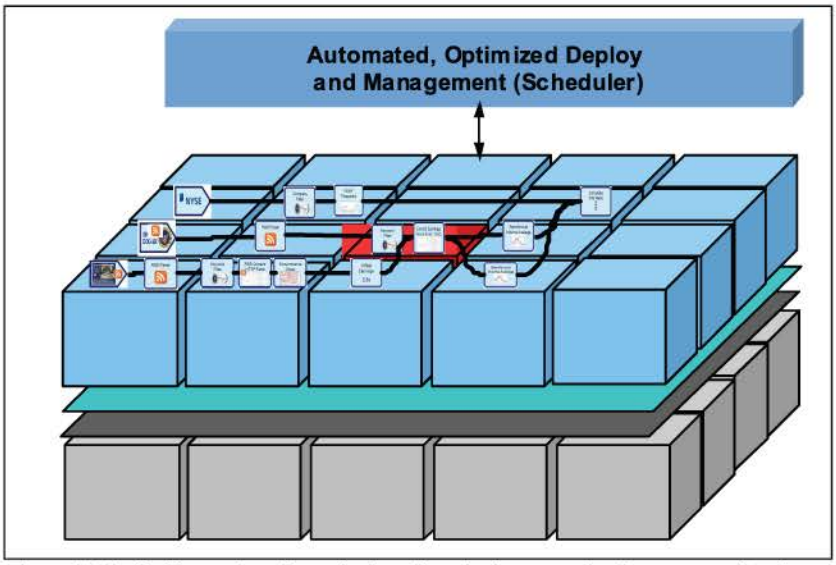


Figure 1-11 An illustration of a typical runtime deployment of a Streams application

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1.2.2 Why use Streams

The architecture of Streams represents a significant change in the organization and capabilities of a computing platform. Typically, stream computing platforms are designed with the lofty goal of achieving success of the following objectives:

- Respond in real time to events and changing requirements
- Continuously analyze data at volumes and rates that are orders of magnitude greater than existing systems
- Adapt rapidly to changing data formats and types
- Manage high availability, heterogeneity, and distribution for the new stream paradigm
- Provide security and information confidentiality for shared information

Although there have been academic and commercial initiatives focused on delivering on the above technical challenges in isolation, Streams attempts to simultaneously address all of them. Streams is on a mission to break through a number of fundamental barriers to enable the creation of solutions designed to deliver on all of these critical objectives.

To do so, the Streams development environment provides a graphical representation of the composition of new applications to make them easier to understand. New applications, or new rules for analysis, can be created dynamically, mapped to a variety of hardware configurations, and then deployed from the development environment to provide the desired flexibility and agility of administration needed within this new paradigm. As analytical needs or rules change, or the priorities and value of data sources shift, the affected portions of the applications can be modified and re-deployed incrementally with minimal impact to the rest of the application. As hardware resource availability grows within the data center, Streams is designed to be able to scale from a single node to one or more high performance clusters having no limit on the number of processing nodes within a cluster. The runtime component continually monitors and adapts to the "state" and utilization levels of its computing resources and the data velocity.

There have been other products engineered to focus on some of the above objectives, many of which center around the analysis of events. You should think of an event as something that happens, such as a temperature reading, a purchase, or an insurance claim. Events might be simple events, such as a purchase transaction, or complex events, such as a combination of purchases with a specific time span.

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In comparison, a data stream is somewhat different. Streaming data is more of a continuous set of never ending readings, for example, the data from an EKG, the output of a video camera, or the sound captured by a microphone. Data streams can be viewed as a continuous stream of events happening quickly and as such there are often correlations and comparisons between stream processing and complex event processing.

IBM has been aware of the potential of using business event processing (processing of both simple and complex events) for quite some time. To get a better idea of exactly how to use this dynamic, IBM has classified seven major opportunities for business event analysis and determined the likely corresponding entry points to consider business event processing systems such as Streams, which are:

- Business Activity Monitoring: Communicating key performance indicators (KPIs) and alerts to business stakeholders
- Information-Derived Events: Identifying correlating events across data stores and data streams
- Business Logic Derived Events: Identifying correlating events across transactions and business processes
- Active Diagnostics: Identifying potential issues and taking action
- Predictive Processing: Identifying future issues based upon business events in context and over time
- Business Service Management: Ensuring IT health so service level agreements are met
- High Volume Stream Analytics: Analysis on high volume data streams in real time

Complex Event Processing (CEP) is an evolution of business event processing. It is primarily a concept that deals with the task of processing multiple business events with the goal of identifying the meaningful characteristics within the entire scenario. In addition, Business Event Processing (BEP) has been defined by IBM and handles both simple and complex events within a business context.

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The goal is always to be able to take advantage of an appropriate action plan in real time. Because of a similar goal within CEP, CEP tools often have the same, or similar, marketing messages as Streams. However, the proof points behind those messages are typically quite different. At the core, these goals of ultra-low latency and real-time event stream processing in real time are true for both. While CEP tools usually achieve response times of under a millisecond, Streams has achieved response times below one hundred microseconds. Both types of tools are able to use parallel processing platforms and techniques, such as partitioning and pipelining, to achieve performance, but the extent of that achievement is far from the same, when comparing a typical CEP tool to Streams.

As we just mentioned, Streams has some similarities to other CEP tools on the market, but it is built to support higher data volumes and a broader spectrum of the data sources used for input. Streams can successfully process millions of messages per second while other CEP tools typically only speak about processing hundreds of thousands of messages per second. Although CEP tools are able to handle discrete events, Streams can handle both discrete events and real-time data streams, such as video and audio. As we have previously described, Streams also provides an infrastructure to support the need for scalability and dynamic adaptability, by using scheduling, load balancing, and high availability techniques that will certainly be key as this information environment continues to evolve.

Like Streams, CEP tools and other products use techniques such as the detection of complex patterns within many events, event correlation and abstraction, event hierarchies, and relationships between events to identify events of events. These complex events allow for analysis across all the layers of information to determine their impact. CEP tools often employ if / then / else-type rules-based analysis. With Streams, you are able to incorporate powerful analytics such as signals processing, regressions, clustering algorithms, and more.

In Table 1-1, we have listed a few characteristics of Streams and CEP to help clarify, and differentiate, them.

Table 1-1 Characteristics comparison of Streams and CEP tools

Complex Event Processing	InfoSphere Streams
Analysis on discrete business events.	Analytics on continuous data streams.
Rules-based processing (using if / then / else) with correlation across event types.	Supports simple to extremely complex analytics and can scale for computational intensity.

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Complex Event Processing	InfoSphere Streams
Only structured data types are supported.	Supports an entire range of relational and non-relational data types.
Modest data rates.	Extreme data rates (often an order of magnitude faster).

As you can see, Streams is fully aligned to the challenges of the Smarter Planet Era. The optimized runtime compiler is architected to manage the extremely high volume of data that makes up the current challenges and will make up the future business landscape by providing the low latency required by real-time analytical processing. The development environment and toolkits are focused on using a client's existing analytics. In addition, the environment will easily allow for the creation of new and complex analytics to find credibility and value for multiple traditional and even non-traditional information sources that are becoming the key elements in our ever-broadening information environment.

1.2.3 Examples of Streams implementations

Even throughout its research and development phase, Streams has been demonstrating success by delivering cutting edge commercial and scientific applications. Many of these applications have shown clients a way to capture the formerly unattainable competitive edge. In addition, many of these early applications are playing a significant role in the evolution of the Smarter Planet.

From the beginning, the intent for the Streams infrastructure was to provide a solid foundation for this broad spectrum of practical applications by being designed specifically to address the fundamental challenges of analysis on streaming data. By being able to continually deliver exceptional performance (for all types of analyses across massive amounts of data) while remaining flexible enough to offer interoperability (with the existing application infrastructures), Streams is positioned for any solution that would benefit from analyzing streaming data in real time. The uses are as varied as the imagination of the analysts involved in almost every industry and initiative.

Some of the early adopters of Streams have developed solutions with life changing potential. To demonstrate some of the types of solutions you can create with the Streams platform, the following sections provide brief examples.

Over the past several years, hundreds of applications have been developed using InfoSphere Streams. The following sections provides a summary of a few applications and highlights the types of usage supported by InfoSphere Streams.

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Example 1: Telecommunications - Call Detail Record mediation and analytics

The challenge of closing certain technology and business gaps has been especially apparent for cellular service providers in Asia. Chips that are embedded in cell phones enable email, texting, pictures, videos, and information sharing using social sites such as Facebook. For each phone call, email, web browse, or text message, cellular phone switches emit call detail records (CDRs). To ensure no data is lost, the switches emit two CDRs for each transaction, which must later be deduplicated for the billing support systems. A rising volume of data caused mediation of CDRs to become ever more difficult to perform in a timely manner. Phone number portability enabled subscribers to move to a competitor at any time. Some sophisticated users even switch between multiple providers at different times within a given day to take advantage of certain promotions. Providers not only needed to reduce the window of processing CDRs to near real time, but also perform real-time analytics in parallel, to predict which customers might leave for a competitor, known in the industry as *churn*. With this real-time insight into customer behavior, providers could take action to retain a higher percentage of customers.

InfoSphere Streams, with its agile programming model, has enabled customers to handle their huge volume of CDRs with low latency, while providing churn analysis on the data at the same time. At one company, a peak rate of 208,000 CDRs per second is being processed with an end-to-end processing latency of under 1 second. Each CDR is checked against billions of existing CDRs with duplicates eliminated in real time, effectively cutting in half the amount of data stored in their databases.

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This example illustrates a key Streams use case: simultaneous processing, filtering, and analysis in real time. High Availability, automated fault tolerance and recovery, along with real-time dashboard summaries, are also currently in use and improving IT operations. Real-time analysis of CDRs is leading to improved business operations by performing things like churn prediction and campaign management to improve the retention rate of their current customers, as shown in Figure 1-12.

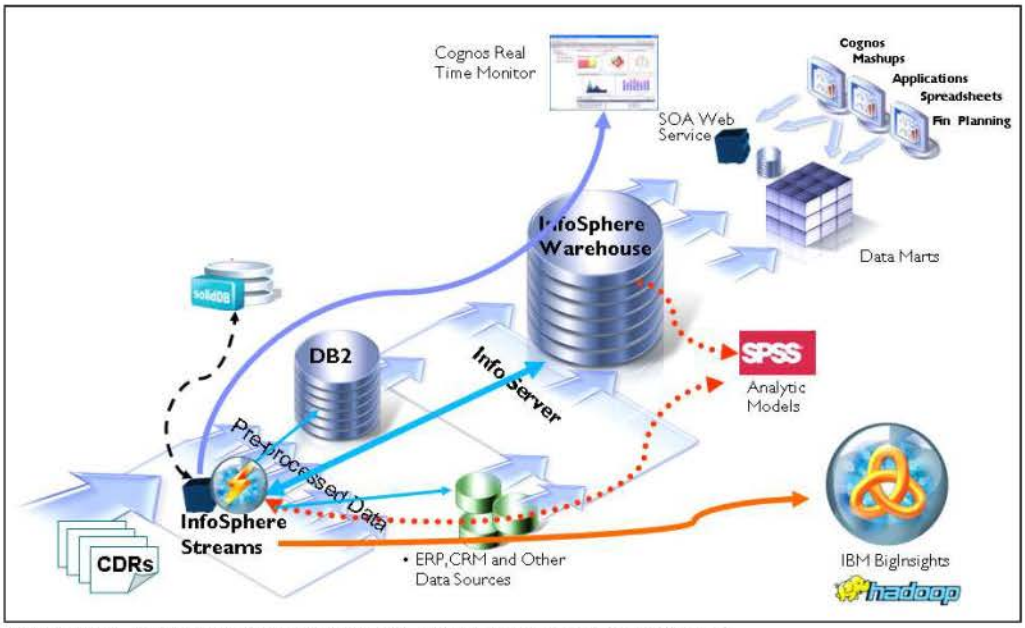


Figure 1-12 InfoSphere Streams Call Detail Record processing architecture

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Example 2: Government - Maintaining cybersecurity in a hostile environment

A key strength of Streams is the ability for Streams to perform analytics on data-intensive streams to quickly and accurately identify the typically small number of items that merit deeper investigation. One example of this use case can be found in the domain of cyber security. A *botnet* is a network of software agents, or robots, that run autonomously and automatically. Botnets respond to Command and Control (C&C) machines, where an underground economy has sprung up to provide per pay access to the botnets for criminal activity. These botnets are evolving rapidly to make it difficult to detect the bots due to fast fluxing networks and encryption. The Shadowserver Foundation tracks known bots, and they estimate that there are thousands of C&C machines, and tens of thousands of bots currently in action today.

InfoSphere Streams was used to analyze IP traffic at a data rate of over 100 megabytes per second of IP traffic and over 10 million domain name server (DNS) queries per hour to generate fast fluxing botnet alerts. InfoSphere Streams not only uses machine learning models, but also models created using historic data in IBM InfoSphere Warehouse for botnet alerts. SPSS Modeler is used to create these historic models. InfoSphere Streams also monitors for model drift. When the attack patterns change, Streams will issue requests to have models updated against the historic data to ensure all parts of the solution are using up-to-date detection models. This use case shows the value of continuously updating the data mining models for both historic and real-time analysis of the data.

Example 3: Financial Services - Finding arbitrage opportunities faster than the competition

Many segments of the financial services industry rely on rapidly analyzing large volumes of data to make near-real time business and trading decisions. Today these organizations routinely consume market data at rates exceeding one million messages per second, twice the peak rates they experienced only a year ago. This dramatic growth in market data is expected to continue for the foreseeable future, outpacing the capabilities of many current technologies. Industry leaders are extending and refining their strategies by including other types of data in their automated analysis; sources range from advanced weather prediction models to broadcast news. IBM developed an InfoSphere Streams based trading prototype running on a single 16 core x86 computer that could processing OPRA data feeds at up to 5.7 million options messages per second, with latencies of under 30 microseconds. Recompiling the application allows it to scale even further when deployed across a cluster of computers.

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Example 4: Health monitoring - Predicting the onset of illness earlier

Stream computing can be used to better perform medical analysis while reducing the workload on nurses and doctors. Privacy-protected streams of medical-device data can be analyzed to detect early signs of disease, correlations among multiple patients, and efficacy of treatments. There is a strong emphasis on data provenance within this domain, which is the tracking of how data are derived as they flow through the system. The "First of a Kind" collaboration between IBM and the University of Ontario Institute of Technology uses InfoSphere Streams to monitor premature babies in a neonatal unit. Data has been collected for more than 18 months from a hospital in Toronto, Canada. Remote telemetry from a U.S. hospital has been operational for a year using the same analytic routines. And earlier this year, additional hospitals in China and Australia began implementation of this solution.

Example 5: Transportation - Getting from here to there faster

IBM is working on an application in the IBM Smarter Cities™ Technology Centre in Dublin, Ireland where InfoSphere Streams receives GPS data once per minute from buses. A real-time display shows all buses as they move through the city. The pilot is working to extend this solution by providing real-time predictions related to arrival times for each bus at each bus stop, which will enable bus riders to better plan when to arrive at the bus stops, reducing waiting times. In the future, a personal travel planner could allow riders to receive recommendations based on real-time traffic monitoring.

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Figure 1-13 provides a picture of such a system.



Figure 1-13 Smarter transportation

In addition, other use cases of InfoSphere Streams are fast emerging in domains such as environmental monitoring and control (wildfire detection and water flow monitoring), energy and utilities industry (synchrophasor monitoring of smart grids and prediction of wind power generation), radio astronomy, x-ray diffraction using synchrotrons, fraud prevention, and many, many more areas.

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2

Streams concepts and terms

In Chapter 1, “Introduction” on page 1we introduced IBM InfoSphere Streams (Streams) from a business and strategic perspective. In this chapter, we look at the next level of detail by discussing and describing the primary concepts of Streams along with many of the terms typically used in a Streams environment. This chapter provides a high-level perspective of Streams that will better enable you to understand the lower levels of detail presented in the subsequent chapters.

We have organized this chapter contents into four major sections. First we discuss the technical challenges found with the types of business problems that Streams is designed to address. However, if you already can easily see where and how Streams can solve those types of problems with which common relational databases and standard extract-transform-load software packages would struggle, you may then choose to advance to 2.2, “Concepts and terms” on page 39, and begin immediately with the ideas that are specific to Streams.

In 2.3, “End-to-end example: Streams and the lost child” on page 48, we give details about one sample Streams application as a means to reinforce the concepts and terms introduced in this chapter, as well as a brief introduction to the numerous tools included with Streams.

Then in 2.4, “IBM InfoSphere Streams tools” on page 58, we introduce the Streams administrative and programming interfaces, some of which were used as we created our end-to-end example.

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2.1 IBM InfoSphere Streams: Solving new problems

The types of business problems that IBM InfoSphere Streams is designed to address are fundamentally different than those regularly addressed by common relational databases and standard extract-transform-load software packages. Consider the following fictitious example scenario.

After scheduling and receiving planned maintenance on your automobile, you pick up your automobile at 7:00 a.m. on your way to work. But then, as soon as your enter the multi-lane highway and proceed to the lane closest to the center of the highway (typically considered the lane for vehicles desiring to travel at higher speeds), your automobile begins running roughly, starts slowing down, and subsequently the engine quits and the automobile comes to a halt.

This is a scenario in which none of us want to find ourselves. It is not only frustrating, but, in this case, is extremely dangerous. Even staying in your automobile cannot be considered safe.

So, you decide to exit the automobile to attempt to get away from the traffic flow. However, the only way you can get off the highway is on foot and by crossing several lanes of high speed traffic, as shown in Figure 2-1. But, there appears to be an endless number of high-speed data points to examine as you begin your decision-making processing. So, how can you leave the highway safely?



Figure 2-1 Examining a stream of traffic

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For the moment, let us think of the situation you are experiencing in terms of a data processing problem. How can you find a safe path to use (time and route) to cross the width of the highway where there are numerous vehicles travelling at various levels of high speed? As is typical of any highway, there are also many types of vehicles of different shapes and sizes. Some of the oncoming vehicles are higher and wider than others, thus obscuring your vision as to what is behind them. How can you make a decision as to when it is safe to cross?

If you did not have a good, continuous live view of the traffic moving on the highway as it is occurring, would you feel comfortable deciding when to cross the road? Even if you had, say, a satellite photo of the roadway that was 60 seconds old, would you feel safe then? Before you answer, consider the fact that satellite images are static. As such, you would need several satellite images to even try to extrapolate the relative speed of each automobile. And, in the time you are performing these extrapolations, the data would have already changed, introducing a measure of latency and resultant inaccuracy into your decision making process.

So what you really need is the ability to see a continuous view of the traffic flowing on the highway, with accurate representations of all the vehicles and their properties (length, size, speed, acceleration, and so on). Can you get that data with traditional data processing capabilities?

What if, for example, you modeled the above situation as an application using a common relational database server (database)? You would discover the following items:

- A database could easily model and record how many and which types of vehicles had passed through given points of the roadway at certain times in the past. The database could easily retrieve this data by location or by most other stored attributes, for as far back as you had chosen to capture and store this data on hard disk (a historical record).
- If you needed to track something resembling real-time (live) data, you would need to make a design choice. Does your model track data by vehicle (its current location and speed), or by section of roadway?

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Note: In a relational database, the data model is generally static. Even if not, certainly the data model is not changing every few seconds or sub-second.

While the data in a standard relational database changes, you do not change the whole of the data frequently. Instead you insert or update a small percentage of the entire contents of the database, where that data resides forever (or at least until it is deleted).

In a relational database, it is the queries that are dynamic. Queries can even be ad hoc (completely unanticipated), but as long as the answer is inside your database (where you have modeled the data to support a given set of questions and program requirements), you will eventually receive a response.

Modeling to track data by vehicle has the advantage that it is finite, that is, there are only so many vehicles that you need to track. If you need to determine conditions for a given section of road, you would use the product of vehicles and vehicle data at a given geographic location. Also, you could create a vehicle record, and update that record on a frequent basis (as frequently as you can afford to from a hardware and performance standpoint).

You could model to track data by location on the roadway. But again, that is a huge amount of data to have to update and record, which may be beyond the limits that your hardware can support. Highways and locations that are modeled and recorded inside databases generally have to give focus to the relatively small number of known exits and merge points. Everything else is extrapolated, which does not help you if your automobile is stranded between recorded points.

However, even with all this modeling, can you satisfy the requirements of the application and get yourself safely off the highway? The short answer is *no*. You need a new application paradigm to satisfy these new requirements. That new paradigm is available, and is know as *stream computing*. As we discuss and describe this new paradigm, you see how using it could satisfy these new types of application requirements.

IBM InfoSphere Streams: A new and dynamic paradigm

As previously stated, a standard database server generally offers static data models and data, while supporting dynamic queries. So, the data is stored somewhere (most often on a computer hard disk), and is persistent. Queries can arrive at any time and answer any question that is contained inside the historical data and data model.

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However, in an IBM InfoSphere Streams environment, you do not have to store data before analyzing it. In fact, with Streams it is generally expected that the observed data volume can be so large that you just could not afford to make it persistent.

In simple terms, Streams supports the ability to build applications that can support these huge volumes of data that have the critical requirement to be analyzed and acted upon with low latency in close to or in real time. For this situation, static models are not sufficient; you need to be able to analyze the data while it is in motion. That is the value of Streams.

Note: The types of questions asked of the data stored in a database (data at rest) are typically quite different than those asked of real-time data that is in flight (data in motion).

For example, a standard relational database could easily answer a question about the retail price of every item sold for the past 6 months. Streams could answer questions about the current sub-second pricing at a world wide auction per sale item by location. The database is appending new data to the database for subsequent queries, while Streams is observing a window of real-time data in flight as it flows from the source.

Streams operates on (ingests, filters, analyses, and correlates) data while the data is still moving. By not having to store data before processing it, Streams addresses the types of applications with requirements for high data volumes and low latency responses.

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Standard database servers generally have a static data model and data, as well as dynamic (albeit often long running) queries. IBM InfoSphere Streams supports a widely dynamic data model and data. The Streams version of a query runs continuously without change. In Figure 2-2 we provide an illustration of these two approaches to data analysis.

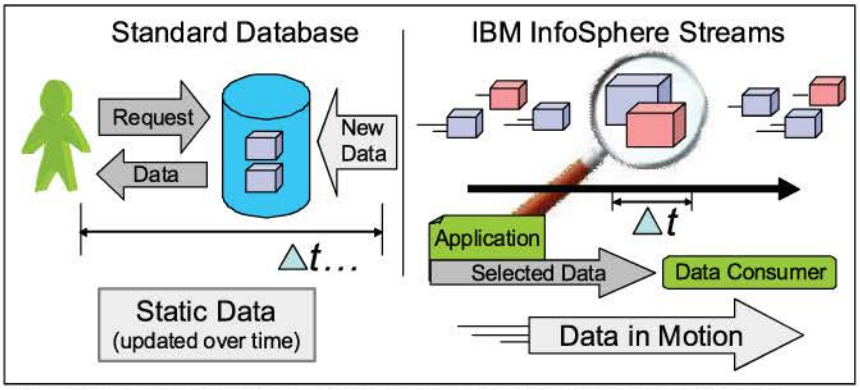


Figure 2-2 A standard relational database compared to IBM InfoSphere Streams

The traditional approach, shown on the left, involves storing data in a standard database, updating that static data over time, and periodically executing queries against that data. By contrast, in the Streams approach shown on the right, the data of interest within the stream is defined, and then processed as it flows by the application. The data is processed while it is in motion and due to its volume or velocity, it is typically not stored.

Queries in IBM InfoSphere Streams are defined by the Streams application, and run continuously (or at least until someone cancels them). In a database environment, a hard disk typically holds the data and the requester is the consumer of that data. In a Streams environment, data meeting the defined criteria is selected as it flows past the application, which then sends it to the appropriate consumer of that data.

Because Streams applications are always running, and continually sending selected data that meets the defined criteria to the consumers, they are well suited for answering *always-on* or *continuous* types of questions. These are questions such as, what is the rolling average, how many parts have been built so far today, how does production at this point in time today compare with yesterday, and other continuous, sub-second response time statistics. Because of the nature of the questions that Streams is designed to answer, it provides join-like capabilities that are well beyond those found in standard SQL.

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Streams easily and natively handles structured and unstructured data, both text and binary formats.

Note: With a standard relational database, the data is stored by persisting it to disk. With IBM InfoSphere Streams, the query (actually a Streams application) sends the appropriate data directly to the consumer of that data. To run a new query (ask a new question) with Streams, you run a new Streams application.

All software environments are composed of three major components: process, memory, and disk. With Streams, it is the process component that consumes the data and develops the response to the queries.

2.2 Concepts and terms

At the simplest level, Streams is a software product. It is well integrated with the operating system for high performance. In a world of database servers, LDAP servers, and J2EE compliant application servers, Streams is a platform with runtime and development components. As such, Streams contains:

- A runtime environment

  The runtime environment includes platform services and a scheduler to deploy and monitor Streams applications across a single host or set of integrated hosts.

- A programming model

  Streams applications are written in the Streams Processing Language (SPL), a largely declarative language where you state what you want, and the runtime environment accepts the responsibility to determine how best to service the request.

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Note: There are many adjectives used to describe computer languages, including the adjective *declarative*. In a declarative computer language, you describe the results (the computation) you desire, without defining how to gather those results (without defining the program flow and control).

SQL, and more specifically SQL SELECT statements, are probably the most widely known example of declarative programming. With an SQL SELECT, you specify only the resultant data set you want to receive. An automatic subsystem to the database server, the query (SQL SELECT) optimizer, determines how to best process the given query, that is, whether to use indexes, or sequential scans, what the table join order should be, the table join algorithm, and so on. The query optimizer decides how to return the resultant query in the fastest time, using the least amount of resources.

In Streams, a Streams application is written in the Streams Processing Language (SPL), which is a declarative language. A Streams application defines the data processing result that you want. The *how to* portion of that execution is determined by the Streams Runtime environment (which includes the scheduler), the SPL Compiler, and to a lesser extent, a number of property and resource files.

The Streams equivalent to a query optimizer arrives in the form of these three entities.

- Tools and monitoring and administrative interfaces

  Streams applications process data at rates higher than the normal collection rate of operating system monitoring utilities can handle. As an example, Streams can process twelve million messages per second with results returned in just 120 microseconds. To handle these types of speeds, a new processing paradigm is required. That paradigm is delivered by InfoSphere Streams.

2.2.1 Streams instances, hosts, host types, and admin services

A Streams instance is a complete, self-contained Streams Runtime environment. It is composed of a set of interacting services executing across one or more host computers.

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Figure 2-3 displays a Streams instance and its member hosts. As with most software systems, the terms found within a Streams-based discussion are either physical or logical. Physical terms exist, and have mass and are measurable, whereas logical terms are typically definitions, and contain one or more physical terms.

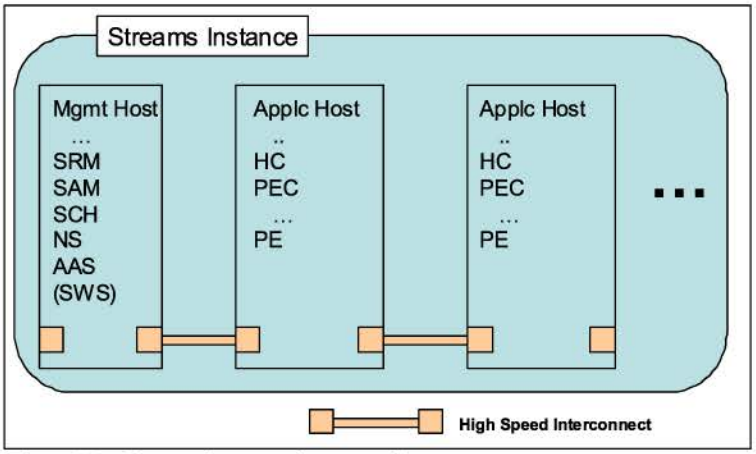


Figure 2-3 Streams instance, hosts, and more

The following comments are relative to Figure 2-3:

- As a term, a Streams instance is logical; a Streams instance serves as a container for the physical entities or host computers.

  Streams instances are started, and then stopped, and the entities contained inside a Streams instance are then modified, compiled, submitted, deployed, and so on.

  From an administrative standpoint, a Streams instance is created and then can be deleted. Creating a Streams instance is a relatively low-cost procedure.

- As a term, a Streams host is a physical term, and usually equates with a single operating system host. In certain contexts, a Streams host is also called a node.

  In order for it to exist, a Streams instance (a logical term) must be composed of one or more hosts (host being a physical term).

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- A Streams host is exclusively one of three types: a Management host, an Application host, or a Mixed-Use host.
  - A Management host executes the resident services that make up the Streams Runtime environment proper; services such as the Streams Authentication and Authorization Service (AAS), which, among other responsibilities, verifies user identity and permission levels.
  - An Application host is dedicated to executing the actual Streams applications that were previously described as being the queries that run continuously inside Streams.
  - A Mixed-Use host executes both resident services (all or a subset of these services) and Streams applications, and are perhaps more common in development environments than in production environments.

    Note: Although the same Streams host could support two or more concurrently running operating Streams instances, that condition is probably not optimal from a performance standpoint.

    There is currently no coordination or communication of any kind between Streams instances. Because high-end Streams instances can easily make full use of system resources, locating two or more Streams instances per host is likely to produce performance bottlenecks.

- Management hosts or Mixed-Use hosts may provide one or more of the following Streams services:
  - Streams Resource Manager (SRM)

    The SRM service initializes a given Streams instance, and aggregates system-wide performance metrics. The SRM Service is also the Service that interacts with the host controller of each application host.
  - Streams Application Manager (SAM)

    The SAM service receives and processes job submission and cancellation requests, primarily through its interaction with the Scheduler (SCH) service.
  - Scheduler (SCH)

    The SCH service gathers runtime performance metrics from the SRM service, and then feeds information to the SAM service to determine which Applications host or hosts are instructed to run given a Streams application (Processing Element Containers).

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Note: The Streams Scheduler Service determines which Application host or Mixed-Use host runs a given Streams application's Processing Elements.

The default Scheduler mode is Balanced. The Balanced Mode Scheduler distributes a Streams application's PEs to the currently least active host or hosts.

The Predictive Mode Scheduler uses resource consumption models (CPU and network) to locate a Streams application's PEs on a given host or hosts, as different PEs are known to consume differing amounts of resources.

  - The Name Service (NS) provides location reference for all administrative services.
  - The Authorization and Administrative Service (AAS) authenticates and authorizes user service requests and access.
  - Streams Web Service (SWS)

    The SWS Service is the first optional Service listed, and provides web communication protocol access to a given Streams instance's administrative functions.

- Application hosts or Mixed-Use hosts may provide one or more of the following Streams services;
  - Host Controller (HC)

    The HC service runs on all Application hosts and Mixed-Use hosts, and starts and monitors all Processing Elements.
  - Processing Element Container (PEC)

    The PEC exists as an operating system binary program. Processing Elements exist as custom shared libraries, and are loaded by PECs as required by given the Streams application definitions.

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Note: Secure operating systems generally disallow one operating system program from having interprocess communication with another program. They also typically disallow sharing concurrent file or device access. Although observed functionality is generally reduced, an upside to this capability is greater process isolation and greater fault tolerance.

To accommodate secure operating systems, IBM InfoSphere Streams supports the concepts of Domains (groups of Application hosts, or nodes).

Other terms in this discussion include the following: Confined Domains, Vetted Domains, or Node Pools, Streams Policy Macros, and Policy Modules. However, these terms are not expanded upon further here.

- The last items related to Figure 2-3 is that it includes the presence of high speed network interconnects, as well as any optional shared file system.

2.2.2 Projects, applications, streams, and operators

In this section, we discuss and describe several of the key terms associated with Stream computing. A few examples are as follows:

- The data is stored in databases, which are used in typical database applications, as called records. In relational terms, the data is stored in a row and column format. The columns are the individually defined elements that make up the data record (or row). In Streams, these data records are called *tuples* and the columns are called *attributes*.

  The primary reason these items are called tuples versus records is to reflect the fact that Streams can process both structured (rows and columns) data and unstructured data (variable data representations, flat or hierarchical, text or binary).
- A stream is the term used for any continuous data flow from a data source. That data is in the form of tuples, which are composed of a fixed set of attributes.
- An operator is a component of processing functionality that takes one or more streams as input, processes the tuples and attributes, and produces one or more streams as output.
- A Streams application is as a collection of operators connected together by streams. A Streams application defines how the run time should analyze a set of stream data.

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The image displayed in Figure 2-4 is taken from IBM InfoSphere Streams Studio. This is the primary developer's workbench for Streams and contains the following items:

- The top portion of the image displays a Streams Processing Language (SPL) source file within the Source Editor View. The bottom portion displays the Application Graph View.
- This Streams application represents the smallest functional Streams application one can create. As such, the following are true:
  - The composite section defines this application's main composite operator, which encapsulates the stream graph that forms the whole program. Main composite operators are self-contained in the sense that their stream graph has no output or input ports. They also have no mandatory parameters.
  - Within the composite section, the graph section defines the stream graph of the application. This consists of one or more operator invocations.
  - The minimum functional Streams application defines at least one Source operator (called a Source) and one destination operator (called a Sink).

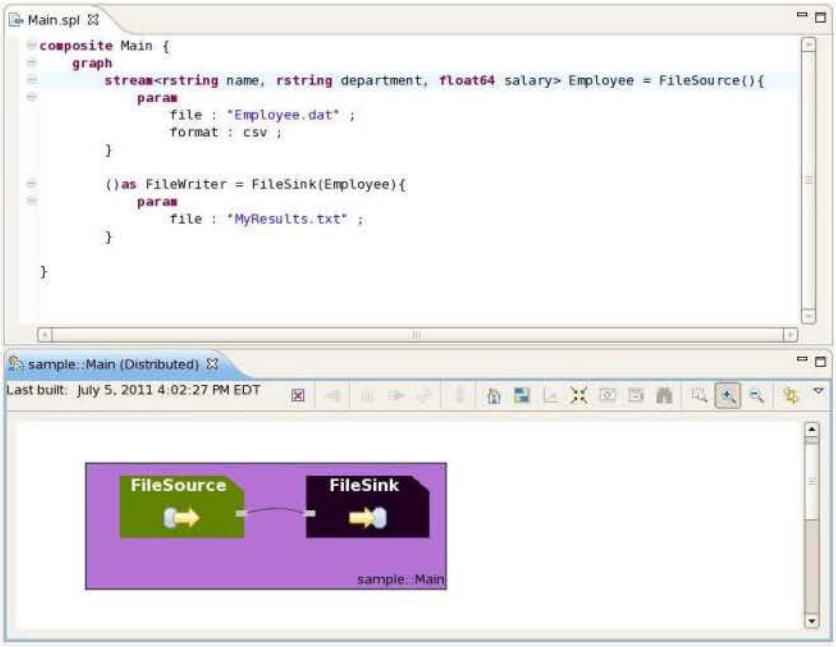


Figure 2-4 Inside Streams Studio - An example Streams application

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Note: Technically, a Streams application does not require a Sink operator, and minimally only requires a Source operator. However, that style of Streams application may not be useful.

The Streams application shown in Figure 2-4 has its own Source operator (which refers to an operating system file) and its own Sink operator (which also refers to an operating system file). As such, it provides a self-contained Streams application.

As more complex Streams applications gain more and more operators, both Sources and Sinks, as well as intermediary operators (not pictured), you might optionally split these larger Streams applications into two or more Streams application Source Files. You then can introduce the Import and Export operators to enable these subset Streams applications to explicitly define their end points.

- The bottom portion of Figure 2-4 displays the Application Graph, which is essentially a logical view of a given Streams application, its operators, and resultant streams.
- A Streams project (not pictured) serves as a container to a Streams application (there is a one-to-one correspondence of project to application). A Streams project contains other properties and configuration settings related to a Streams application.
- As a term, the word *stream* represents the actual flow of tuples from operator to operator.

  Generally, Source operators output one stream, which may be consumed by one or more downstream operator(s).
- The definition of the data attributes (count and associated data types) being consumed by, or output by, a given operator is referred to as a schema definition (schema).

  Generally, most operators can accept only one input (schema definition) and produce only one output (schema definition). An operator can accept multiple input streams, as long as each is the same in its schema definition.

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Note: Additional Source and Sink operators are available in the Database, Financial Services, Internet, Mining, and SPL Standards toolkits. These operators include ODBC connectivity to relational databases, stock market data feeds, and support for HTTP, RSS, FTP, and other communication protocols.

If you still have not found support for your given data source or data target, Streams also allows you to create user-defined sources and sinks.

2.2.3 Applications, Jobs, Processing Elements, and Containers

We have previously defined an InfoSphere Streams application. However, this represents only the definition (the declaration) of a given request for service from inside the IBM InfoSphere Streams platform. We need further terms to define the instantiation and execution of these objects.

A Streams application can be submitted for execution in the form of a Streams Job. Generally, there is a one-to-many relationship of applications to jobs. As examples, an application may not be running (zero jobs), running only once (one job), or there may be several copies of the same application running (many concurrent applications, or more accurately, many concurrent jobs). Applications can be defined to accept runtime parameters, so that each of the concurrently executing jobs are performing distinct processing.

Job is a logical term, and exists in the form of one or more Processing Elements (PEs). Where the Processing Element Container (PEC) service runs on each Application host or Mixed-Use host, the PEC exists as an operating system binary program. PEs exist as shared libraries that are loaded by PECs, and then run.

Note: Ultimately, the discussion of Processing Element Containers (PECs) and Processing Elements (PEs) leads to a discussion of process architecture.

Rather than throwing dozens or even hundreds of executable processes at the operating system, and asking the operating system to perform process scheduling (with all of the operating system's associated and costly process context switching), the Streams Runtime environment provides this task, which is critical towards achieving ultimate performance.

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2.3 End-to-end example: Streams and the lost child

In this section, we provide a sample IBM InfoSphere Streams (Streams) application. The business problem used in this end-to-end example is described as follows:

At upscale alpine ski resorts, you may find that your room key not only opens the door to your guest room, but also serves as a charge card at the resort retail outlets, game rooms, and so on. This card also allows you access to the ski lifts.

Besides tracking customer preferences, this system can also be used to locate lost or missing children.

In the example application, we receive three input data feeds:

- Door scans, including the guest rooms, pool and other areas
- Retail purchases, which also indicate location, and entry to the ski lift lines

The Streams application we detail keeps the last known location of each child on the resort property, and matches that data with requests to find lost or missing children.

In the real world, these input data feeds would arrive from various live systems. To better enable you to recreate this application in your environment, the example below uses ASCII text files. The sample contents of these files are shown in Example 2-1.

Example 2-1 Sample data used in this example - Input and output

```
                    4th Col
                    here is
Door Scans          Boolean
                    1=Minor
Lname,Lname,x,x,ifIsMinor,Timestamp,Location
Morgenson,Sally,5,0,0,2010-02-14 10:14:12,Pool
Tanner,Luis,12,1,0,2010-02-14 10:14:12,Patio
Irwin,Mike,2,2,1,2010-02-14 10:14:12,Pool
Davidson,Bart,0,0,1,2010-02-14 10:14:13,Club House
Thomas,Wally,0,0,0,2010-02-14 10:14:14,Exercise Room
Williams,Eric,0,0,0,2010-02-14 10:14:13,Club House
Ignacio,Juan,3,1,0,2010-02-14 10:14:14,Game Room
Ryne,Paul,0,0,0,2010-02-14 10:14:13,Club House
Irwin,Mike,2,2,1,2010-02-14 10:14:14,Laundry Room

Lift Lines
```


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```
Lname,Fname,Timestamp,Location,Minor
Davidson,Frederick,2010-02-14 10:13:55,Garfield Lift,N
Samuel,Corky,2010-02-14 10:13:55,Pioneer Lift,N
Ignacio,Juan,2010-02-14 10:13:55,Pioneer Lift,N
Stevens,Sam,2010-02-14 10:13:55,Tumbelina Lift,N
Bartolo,Izzy,2010-02-14 10:13:55,Breezeway Lift,N
Edwards,Chuck,2010-02-14 10:13:55,Pioneer Lift,N
Sylvestor,Hugo,2010-02-14 10:13:55,Tumbelina Lift,Y
Thomas,Wally,2010-02-14 10:13:55,Tumbelina Lift,N

Cash Register Swipes

Lname,Fname,Location,Timestamp,Minor
Green,Roxanne,Soda Shop,2010-02-14 09:23:56,N
Balmos,Fred,Gift Shop,2010-02-14 10:11:51,Y
Morgenson,Sally,Cafeteria,2010-02-14 10:14:08,N

Lost Children

Lname,Fname,Who-called
Irwin,Mike,Mum
Dewey,Ian,Dad

Results File

"Irwin","Mike","Mum","Laundry Room","2010-02-14 10:14:14"
"Dewey","Ian","Dad","",""
```

The following items relate to Example 2-1 on page 48:

- Five total files are displayed.
- The three input files called Door Scans, Lift Lines, and Cash Register Swipes, represent normal guest activity at the alpine ski resort, such as passing through a secure doorway, purchasing something, or entering the lift line.

  Each of these three files is modeled differently, with different attribute order and data types. A multi-attribute primary key is present in the form of a combination of last name (Lname) and first name (Fname) combined.

  A mixture of one/zero, and Y/N, represents the identification of children versus adults. This system is designed only to locate missing children.
- A fourth input file (Lost Children) contains requests by parents to locate their missing child.
- The fifth file represents the application result set.

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In the case of Mike Irwin, the system reported a last known location, while the system did not have a known location for Ian Dewey.

2.3.1 The Lost Child application

Example 2-2 displays the self-contained Streams application that is used as an example throughout the remainder of this section.

Example 2-2 Self-contained Streams application

```
composite Main {
   type
      DoorScanSchema = tuple< //
      rstring lastName, //
      rstring firstName, //
      int32 unused1, //
      int32 unused2, //
      int32 ifIsMinor, //
      rstring timeStamp, //
      rstring location> ;
      //
      LiftLineSchema = tuple< //
      rstring lastName, //
      rstring firstName, //
      rstring timeStamp, //
      rstring location, //
      rstring ifIsMinor> ;
      //
      RegisterSwipeSchema = tuple< //
      rstring lastName, //
      rstring firstName, //
      rstring location, //
      rstring timeStamp, //
      rstring ifIsMinor> ;
      //
      MergedChildSightingsSchema = tuple< //
      rstring lastName, //
      rstring firstName, //
      rstring timeStamp, //
      rstring location, //
      boolean isMinor> ;
   graph
      stream<DoorScanSchema> DoorScans = FileSource(){
         param
            file : "DoorScans.txt" ;
```


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```
            format : csv ;
            hasHeaderLine : true ;
            hasDelayField : false ;
            parsing : strict ;
      }

      stream<MergedChildSightingsSchema> MergeDoorScan =
Functor(DoorScans){
         output
            MergeDoorScan : isMinor = (ifIsMinor == 1) ;
      }

      stream<LiftLineSchema> LiftLines = FileSource(){
         param
            file : "LiftLines.txt" ;
            format : csv ;
            hasHeaderLine : true ;
            hasDelayField : false ;
            parsing : strict ;
      }

      stream<MergedChildSightingsSchema> MergeLiftLine =
Functor(LiftLines){
         output
            MergeLiftLine : isMinor = (ifIsMinor == "Y") ;
      }

      stream<RegisterSwipeSchema> RegisterSwipes = FileSource(){
         param
            file : "CashRegisterSwipes.txt" ;
            format : csv ;
            hasHeaderLine : true ;
            hasDelayField : false ;
            parsing : strict ;
      }

      stream<MergedChildSightingsSchema> MergeRegisterSwipe =
Functor(RegisterSwipes){
         output
            MergeRegisterSwipe : isMinor = (ifIsMinor == "Y") ;
      }

      stream<MergedChildSightingsSchema> MergedChildSightings =
Functor(MergeDoorScan, MergeLiftLine, MergeRegisterSwipe){
         param
```


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```
            filter : isMinor == true ;
      }

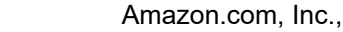
      stream<rstring lastName, rstring firstName, rstring whocalled>
LostChildren = FileSource(){
         param
            file : "LostChildren.txt" ;
            format : csv ;
            hasHeaderLine : true ;
            hasDelayField : false ;
            parsing : strict ;
            initDelay : 2.0 ;
      }

      stream<rstring lastName, rstring firstName, rstring whocalled,
rstring location, rstring timeStamp> JoinedRecords =
      Join(LostChildren as LHS ; MergedChildSightings as RHS){
         window
            LHS : sliding, count(0);
            RHS : partitioned, sliding, count(1);
         param
            algorithm : leftOuter ;
            partitionByRHS : RHS.lastName, RHS.firstName;
            equalityLHS : LHS.lastName + LHS.firstName ;
            equalityRHS : RHS.lastName + RHS.firstName ;
         output
            JoinedRecords : lastName = LHS.lastName, firstName =
LHS.firstName, whocalled = LHS.whocalled, location =
            RHS.location, timeStamp = RHS.timeStamp ;
      }

      ()as FileWriterJoinedRecords = FileSink(JoinedRecords){
         param
            file : "JoinedRecords.txt" ;
            format : csv ;
      }

}
```


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2.3.2 Example Streams Processing Language code review

The following items are part of a code review related to Example 2-2 on page 50:

- The composite section provides the name for this Streams application, which is titled “Main”.
- The type section defines the schemas of the streams within this application.
- The graph section contains Streams Processing Language declarative commands proper, and makes up the majority of this file.
- There are five schema definitions within the type section. Any of these schema definitions could have been placed inside a given operator and could have been functionally equivalent. The purpose of defining them once at the start of the application is to increase source code readability, and increase code re-use. As you can see, some of the schema definitions are used multiple times inside this file.

  A schema definition has the general form of an attribute data type and then attribute name (comma and repeat). The attribute data types presented in Example 2-2 include String, int32, and Boolean.

  Note: The Streams Processing Language includes 22 or more simple data types, as well as collection types such as list, set, map, and tuples.

Reading data: Source stream operator

The first real statement of SPL source code in Example 2-2 on page 50 begins with the text `stream<DoorScanSchema> DoorScans = …` and ends with the trailing curly brace `}`.

- This statement defines a source (input) stream for this Streams application. This FileSource() operator is an ASCII text file reader.
- The syntax begins as “stream”, a schema definition, and then a stream name (with the stream name DoorScans).

  If any further operator in this application wants to consume the output of this operator, it could do so by using the stream name DoorScans. Generally, any operator can automatically support multiple consumers of the output stream that it produces.
- The stream name is followed by the output attributes specification to this operator. Here we could explicitly specify attribute names and attribute data types, but optionally make reference to a type declaration above and call it DoorScanSchema.

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- The text following the "param" keyword specifies modifiers to this operator; specifically, we set the file name, input file values are delimited with commas, the file has a header line, and the operator does not include a delay interval and should be parsed for strict adherence to data types.

Filtering and mapping attributes: Functor operator

The second statement of SPL source code in Example 2-2 on page 50 begins with the text `stream<MergedChildSightingsSchema> MergeDoorScan = …` and ends with a trailing curly brace `}`.

- This Streams operator is of type Functor(). In its simplest form, an SPL Functor() operator is similar to a Transform operator in a standard extract-transform-load software package.
- This Streams operator receives five input attributes, as determined by its source stream (DoorScans). The Source operator (and source stream) sends five attributes, so we receive five attributes.

  The Functor() operator compares the value of the int32 input attribute named "ifIsMinor" to the literal value of "1".

  If the value of this input attribute equals 1, then the Boolean output attribute isMinor is assigned the value of "true".

Note: This Streams operator also outputs five Attributes, as determined by the Schema Definition named MergedChildSightingsSchema.

These source and output Schema Definitions for this operator are equal in Attribute count, and also in the collection of most attribute names. These two Schema Definitions do differ, however, in the attribute data type for the last attribute, which is named ifMinor. We change (recast) that data type from Int32 to Boolean to demonstrate this technique (and also to make the definition of this data stream consistent with the other data streams we manipulate in a related manner in the following sections).

Note: Algorithmically, what we are doing here is recasting this input Attribute data type. Because computers cannot assume that a numeric one should translate to a Boolean "true", we have this block of statements.

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Four more operators

The next four Streams operators in this application are as follows:

```
stream<LiftLineSchema> LiftLines = …
stream<MergedChildSightingsSchema> MergeLiftLine = …
stream<RegisterSwipeSchema> RegisterSwipes = …
stream<MergedChildSightingsSchema> MergeRegisterSwipe = …
```

These operators provide similar functionality to the two Streams operators we previously described, but demonstrate no new techniques. The next significant operator we describe is named *MergedChildSightings*.

Merging (input) Streams: (Any) operator

The Streams Processing Language statement that begins with the text `stream<MergedChildSightingsSchema> MergedChildSightings = …` is also an operator of the Functor type. We need an operator of the Functor type to both merge the sources of location data and also to apply a filter condition (isMinor = "true"). This Functor operator gives us our three main, merged input data streams as a single output stream.

Reading the list of lost children

Consider the following SPL statement:

```
"stream<rstring lastName, rstring firstName, rstring whocalled>
LostChildren = …"
```

In this statement, we read the file containing the names of the children who have been reported as lost. Note the additional "initDelay" parameter used with the FileSource operator.

Note: In a real situation, this Streams application would start and run for a long time. In this simple example, we are using operating system text files with only a few lines of data. The challenge in testing or developing in this manner is the sequencing of multiple operating system programs and multiple Streams PECs.

In this example, we are reading from four small input files, and it could happen that we read from the single file containing the request to find a lost or missing child (and perform the join) before we ever load the three files that contain the current child location (and thus return zero joined tuples).

To better accommodate development and testing on such a small sample, the operator that reads the missing children names includes the modifier named initDelay. This modifier causes this Source stream to wait two seconds before completing its initialization.

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Joining, aggregating, or sorting static (normal) data

The next requirement in our Streams application is to compare the tuples of the known child locations with a request to locate a child. This task is completed using an SPL Join operator. However, joining, aggregating, or sorting streamed data is fundamentally different than joining or aggregating data in a static data repository. In this section, we describe that challenge.

When sorting a standard list of data, you cannot output any of the tuples until you have first received all of those tuples.

However, based on that statement, what if you are receiving a list of tuples to be sorted alphabetically, but the last tuple to be received starts with the letter "A" (and should be output first)? Sorting data has this requirement, and so does aggregating data, which has an implied sort. For example, when aggregating by department, you first sort the list of company-wide data by department.

Joining data also implies this condition, because you nearly always sort at least one side of the joined lists to achieve better performance.

The assumption here, however, is that you know where or when the end of the data is located or received. Remember, you need to receive the last row before you can complete a sort. Because streaming data never terminates, how then do you sort (or aggregate, or join)? The answer is to create windows, or marked subgroups of the data received.

With InfoSphere Streams, an input data stream may never terminate, and yet you still need to join data, aggregate data for given subgroups, or sort data within given subgroups. To accomplish this program requirement, Streams defines the concept of (moving) windows of data.

Joining, aggregating, or sorting streamed data

In an endless stream of data, IBM InfoSphere Streams allows data to be promoted into subgroups, called windows (of data), by defining a number of conditions. Here is a list of some of the possible conditions:

- By row count
- By elapsed time
- By a marker in the stream sent by an upstream operator (this marker is referred to as punctuation)
- By an evaluation expression against the attribute values
- A combination of the above conditions

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With Streams, there are two types of windows: tumbling and sliding. A tumbling window fills with data, performs or supports whatever operator is specified, and then moves to an entirely new window (which is an entirely new sub grouping) of data. It tumbles forward through the data, end over end.

For example, a tumbling window could be used to aggregate streaming data, and report every time a new key value pair has changed its descriptive attributes. From our alpine ski resort and lost or missing child example, the windows would report every time a child's location changes. This window would be tumbling because it dumps one key-value-pair tuple in favor of another.

A sliding window fills with its first sub-grouping of data, performs or supports whatever operator it is an element of, then continues with this same data, adding it incrementally, or sliding, as new data is received.

Note: As previously stated, Streams windows are used with at least three Streams operators, including Aggregate, Sort, and Join. Often you might choose to model a window using Aggregate or Sort, and then apply this definition to the Join operator that simultaneously manages two Streams, which are the two sides of the join pair.

Much like standard relational databases, Streams supports full joins, and left and right outer joins. Streams also allows joins on more than just relational algebra, meaning that a left side expression can evaluate to true, and it will join with all right side expressions that are also true, without either side having to be equal to each other.

Further, Streams supports full intersections of data, which means that, by default, Streams attempts to join all tuples from the left side of the join pair to the right side of the join pair, and then joins all right side tuples with the left side tuples.

In our example use case, we want an outer join and return the child's location if it is known; otherwise we return null. We still want a response, even if it is null. However, we want only to join a child identifier with location. In Streams terminology, this is referred to as a *one sided join*.

Joining tuples: Join operator

At this point, we have met all of the prerequisites for our Streams Join operator, and continue with Example 2-2 on page 50. This discussion continues with the source line that begins as follows:

```
stream<rstring lastName.., > JoinedRecords = Join(…"
```


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Where:

- This operator uses an explicit schema definition. We could have used a predefined schema definition, but instead we decided to show an explicit schema definition.
- The windows expression proper is in the parentheses following the Join keyword. It states the following:
  - LostChildren lists a window size of zero tuples. MergedChildSightings is listed with a window size of 1 tuple per child.
  - That condition makes this a one-sided Streams Join, with the behavior that the join is only triggered on the arrival of LostChildren tuples, and not MergedChildSightings tuples.

All Join operators use only sliding windows, as is the nature of a join.

Writing data: Sink operator

The last Streams operator in Example 2-2 on page 50 is as follows:

```
() as FileWriterjoinedRecords = …
```

It writes the observed result to an operating system ASCII text file, with sample results displayed at the bottom of Example 2-1.

Although we write to a file here to simplify this example, in a real situation we could have several concurrent subscribers to this output stream, including electronic pagers, event alerts, text message generators, and so on.

2.4 IBM InfoSphere Streams tools

IBM InfoSphere Streams offers a combination of command-line tools and graphical tools (web-based and fat client), as well as tools to perform administrative and monitoring functions, and application development functions, as examples. In this section, we detail two of those tools:

- IBM InfoSphere Streams Studio (Streams Studio)

  An Eclipse based developers and administrator's workbench.

- streamtool

  A command-line interface program that is used to perform many tasks, such as listing Streams instances, and starting and stopping instances.

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2.4.1 Creating an example application inside Streams Studio

In this section, we provide the steps used to develop the sample Lost Child application using the Streams Studio developer's workbench. This example should give you a better understanding of IBM InfoSphere Streams Studio. In the development of the sample application, the following assumptions are made:

- The complete IBM InfoSphere Streams product is installed, including a base Eclipse installation with Streams Studio plug-ins.

  The operating system platform in the example is Red Hat Enterprise Linux Version 5.x.

- You have created the four sample input files displayed in Example 2-1. Add them to a folder in Eclipse later.

Complete the following steps:

1. IBM InfoSphere Streams Studio exists as a collection of plug-ins to the Eclipse developers workbench. To run Streams Studio, launch Eclipse.

   Note: Eclipse is an open source and extensible developer's workbench. As IBM InfoSphere Streams Studio is based on Eclipse, it inherits many Eclipse terms and concepts.

   In Eclipse, a given parent directory contains all of your Projects, and any metadata related to work bench preferences. In Eclipse, this parent directory is called your Workspace. Project is also an Eclipse term, and is thus inherited by Streams. In Streams, there is a one to one relationship of Streams project to Streams application.

   If you are prompted to select a Workspace when launching Eclipse, select the default value and click the **OK** button.

   If this is your first time that you are running Eclipse, you may receive a Welcome window. Feel free to close it.

2. You need to create a small number of Streams objects before you can begin entering Streams Processing Language statements. To accomplish this task, complete the following steps:

   a. From the Studio menu bar, select, **File** → **New** → **Project**. A dialog box opens.

   b. Select **InfoSphere Streams Studio** → **SPL Project** → **Next**.

   c. Give this new Streams project a name and click **Finish**. If you are prompted to change Perspective, click **Yes**.

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Note: Perspective and View are additional Eclipse terms.

A View in Eclipse is a distinct area of the window, and in other environments might be called a panel or frame. There are so many Views in Eclipse that they are organized into groups of Views called Perspectives.

Streams Studio provides two Perspectives with its Eclipse plug-ins, and a number of Views.

If this is the first time you are running Eclipse and creating a Streams Project, you may receive a prompt to change Perspectives. If so, click, **Yes**.

3. At this point you are ready to enter Streams Processing Language (SPL) statements.

   To begin, you may first create either the sample Streams application shown in Figure 2-4 on page 45 or Example 2-2 on page 50. To do so, create an SPL source file by selecting **File** → **New** → **Other** → **SPL Source File** → **Next**.

   In the dialog box that opens, pick your newly created SPL project. Leave the other fields unchanged and click **Finish**.

   In the resulting Main.spl editor, enter the SPL source code. As you do, be aware of the following items:

   a. If you produce an error in your syntax, a red marker highlights the source of the problem. For a more detailed description of the error, you may also move to the Problems View.

   b. While entering statements in the Editor View, you can enter Ctrl+Spacebar to produce context sensitive help. You are prompted with a next option or continuation of the current command or modifier.

   c. You are done when your SPL Source code matches the statements you have been entering from the example, you have zero errors after saving the file, you have copied your four input files into the data folder, and your Project Explorer View is what is shown in Figure 2-5 on page 61.

4. To run the Streams application, complete the following steps:

   a. Click **Streams Explorer View** tab, and in the list shown, right-click **Instances** and select **Make instance...**. Enter the name MyInstance and click **OK**.

   b. Navigate to the MyInstance entry under Instances, right-click it, and pick **Start instance...**. Allow the instance to start before continuing.

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c. Return to the **project explorer view**, right-click **Distributed [Active]**, and select **Launch**. Use the default values shown in the resulting dialog box and click **Continue**. Click **Yes** if you are prompted to save any unsaved changes.

d. After 5 or 10 seconds, select the data folder under Resources and press F5. You should see a new file named `JoinedRecords.txt`. Open the file to confirm that it contains the expected output.

These step execute your Streams application. As Streams jobs never terminate, you should navigate to the 0:Main entry under Jobs on the Streams Explorer tab, right-click **0:Main**, and select **Cancel job**.

In the following pages, we show a number of images from the IBM InfoSphere Streams Studio. For example, Figure 2-5 displays the Project Explorer View.

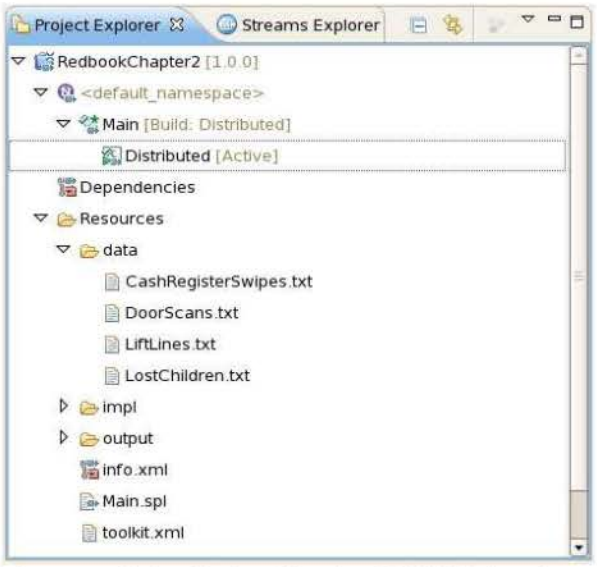


Figure 2-5 Project Explorer View from IBM InfoSphere Streams Studio

Where:

- The Project Explorer View operates like most file explorer interfaces. The highest level object displayed in this View are Streams projects, followed by the given contents of the project, the SPL source file, and so on.
- Figure 2-5 displays a data subdirectory where all source and target operating system data files are located.

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- Other files displayed in Figure 2-5 on page 61 contain configuration settings, and commands to start and stop the given Streams instance, and to submit and cancel the associated Streams application (job).

Figure 2-6 shows the Streams Application Graph View from InfoSphere Streams Studio.

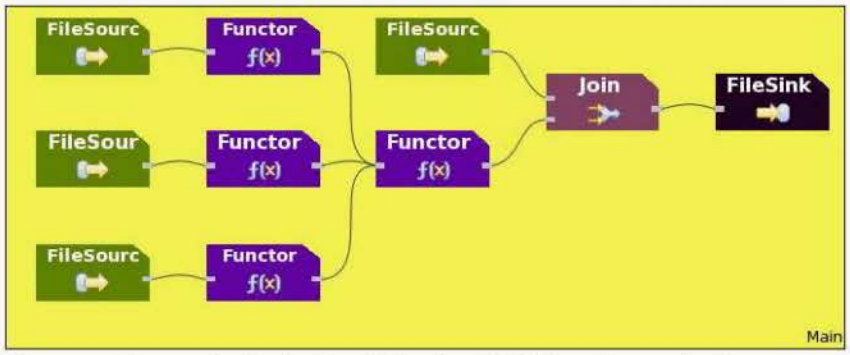


Figure 2-6 Streams Application Graph View from InfoSphere Streams Studio

Where:

- The graphic in Figure 2-6 shows the logical design of the given Streams application from an operator and Stream perspective.

  If you right-click and select **Open Source** any of the operators, your cursor will move to that point in the Streams application source file.

- You can use the Streams application Graph to ensure that all of your operators are connected as you intend them to be. An operator with no input/output Stream most likely indicates you have misspelled a given Stream in your SPL source file.

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Figure 2-6 on page 62 displays the logical design of a given Streams application, but Figure 2-7 shows it executing.

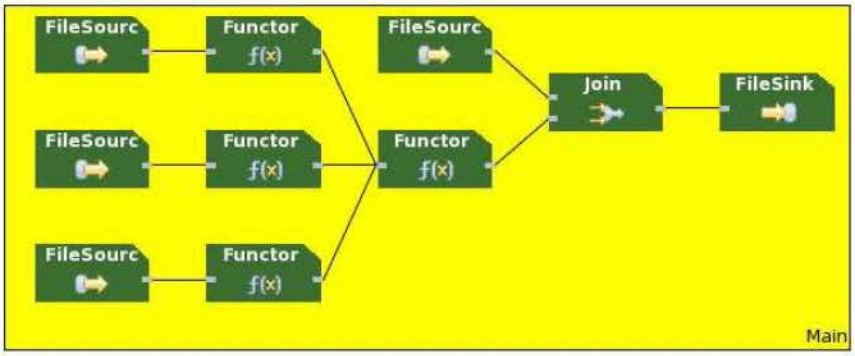


Figure 2-7 Streams Live Graph View from IBM InfoSphere Streams Studio

Where:

- The colors of the displayed operators change as the operator state changes. If you are not seeing the color changes, this is most likely due to the fact that this application runs quickly.
- Clicking an operator displays metrics about the number of tuples processed and other information.

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The Metric View is shown in Figure 2-8, which shows the most detailed and low-level performance statistics.

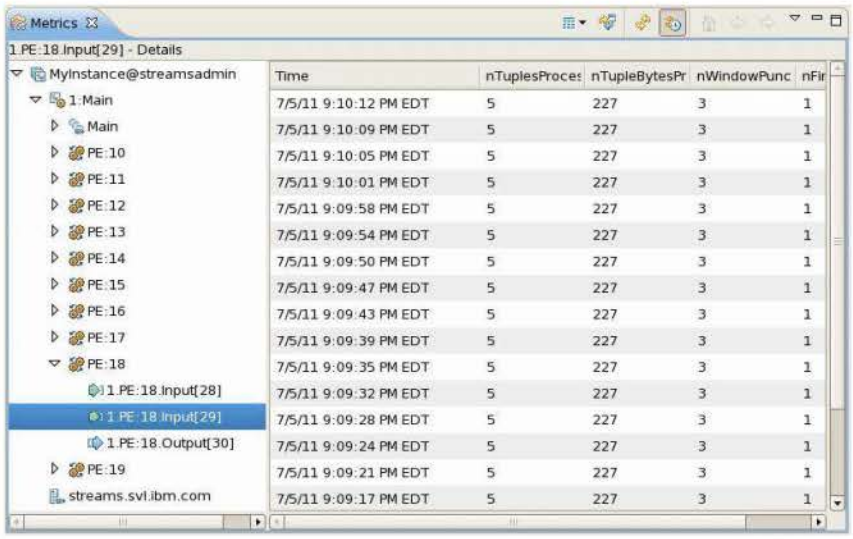


Figure 2-8 Streams Live Graph Outline View from IBM InfoSphere Streams Studio

The Streams Metric View displays rows counts, bytes, and so on, operator by operator. This View is handy for debugging, as well as for monitoring, your Streams application.

You can also concurrently run this View with the Streams Application Graph, moving back and forth as you click various elements.

Using streamtool

The IBM InfoSphere Streams streamtool offers a command-line (character based) interface that can also be used to accomplish all the steps we performed in previous sections. Most invocations in the streamtool require that you supply a Streams instance id-name. If you do not know your Streams instance id-name, you can run the following from the command line:

```
streamtool   lsinstance
```

(For clarity, lsinstance is “L S Instance” in lowercase and is one word.)

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Note: If your Streams instance id-name contains a special character, for example, the @ sign, then you must always enter this id-name inside a pair of double quotes. Otherwise, your operating system command interpreter will observe and process those special characters.

The above command reports all currently running Stream instances on the given server. If you do not know your Stream Instance id-name and that instance is not currently running, you may then start the instance inside InfoSphere Streams Studio and then return to this point.

To start or stop a given Streams instance, run the following commands:

```
streamtool   startinstance   -i   id-name
streamtool   stopinstance   -i   id-name
```

Note: It is common for new developers to exit the Streams Studio design tool and leave their Streams instance running, and then not know how to terminate or even restart the Streams instance.

To force a shutdown of the Streams instance, run **`streamtool stopInstance`** and append the -f flag.

By default, the Streams instance SWS service is not running, but is still required to run the IBM InfoSphere Streams Console, which is a web-based application. To start the Streams SWS service, complete the following steps:

1. To obtain a list and location of all running Streams Services, run the following command:

   ```
   streamtool   lshost   -i   id-name  -long
   ```

   The sample output below, indicates that SWS is not running:

   ```
   host          Services
   host-x        hc, aas, nsr, sam, sch, srm
   ```

2. To start the SWS Service, run the following command:

   ```
   streamtool   addservice   -i   id-name    --host    host-x   sws
   ```

3. To get the fully qualified URL that allows access to the Streams Console, run the following command:

   ```
   streamtool   geturl   -i   id-name
   ```


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Enter the return value inside a supported web browser, as shown in Figure 2-9.

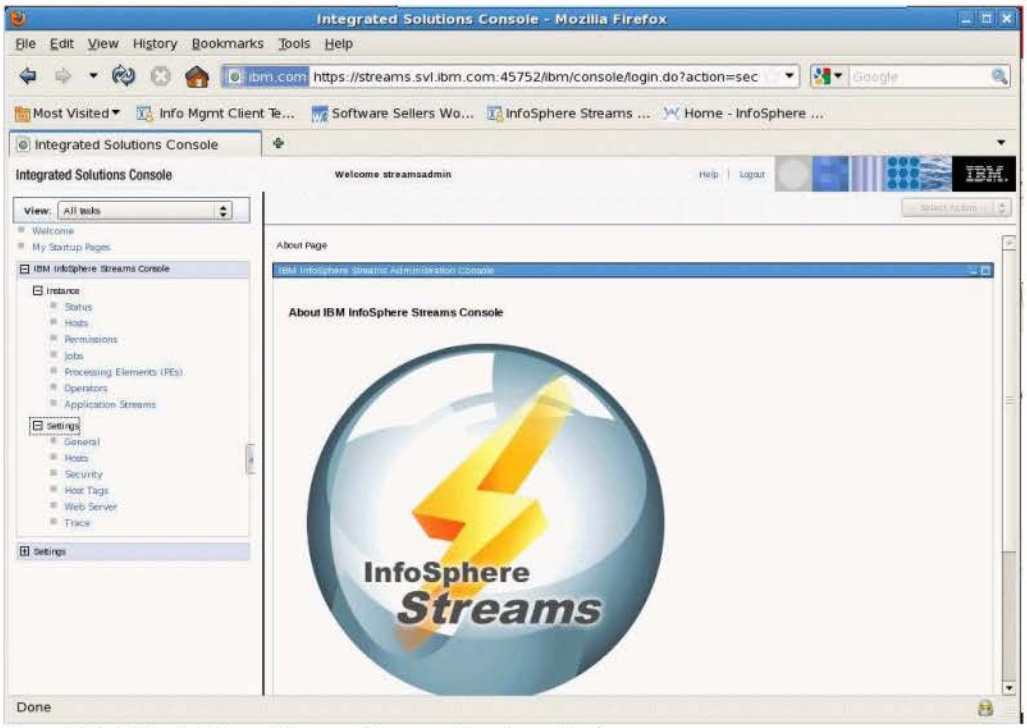


Figure 2-9 IBM InfoSphere Streams Console - A web application

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3

Streams applications

In previous chapters of this book, we introduced you to Streams applications, which are composed of a combination of data streams and operators on these streams that allow InfoSphere Streams to ingest, process, and output data.

In this chapter, we provide a closer look at Streams applications, and outline the activities required to design a well performing application. The design process will lead you to consider the purpose, inputs, outputs, and dependencies of the system in question. We also outline features to address the performance requirements that should be considered during application design. In addition, we contrast Streams application development with traditional application development and highlight a number of novel attributes of Streams applications.

From early experience with implementing Streams applications, we list a number of use cases and example design patterns that should help you understand the best positioning and use of the Streams platform and enable new developers to better relate their requirements for established systems.

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The scalable, continuous processing model of InfoSphere Streams makes it ideal for the following types of applications:

- RIGHT NOW applications: In RIGHT NOW applications, an action needs to be taken as soon as there is enough information to predict or detect an opportunity. Examples of RIGHT NOW applications include preventing cyber security attacks, providing a better experience for customers at the point of contact, taking advantage of a trading opportunity in capital markets, and stopping a security threat.
- MORE CONTEXT applications: In MORE CONTEXT applications, there is a desire to take advantage of data that would have been too time sensitive or too expensive to incorporate using previous computing platforms. By automating the analysis in a continuous way without storing data, the Streams platform can deliver insights from this data that give a competitive advantage. Examples of MORE CONTEXT applications are those that enhance customer interactions with context from social media, such as blogs and tweets, or security applications that use computers to simultaneously examine numerous video streams, saving the streams and alerting humans only when something unusual happens.
- DYNAMIC INSIGHT ASSEMBLY LINE applications: In assembly line applications, the application naturally can be structured much like a manufacturing assembly line operating on data items element by element as the elements stream by. These applications can be dynamically reconfigured based on data or application needs. One example of this kind of application is Call Detail Record (CDR) processing for telecommunications where a well-defined set of steps are performed to mediate and remove duplicates from the records. CDR applications can be extended by providing features such as real-time summary statistics or immediate offers for customers based on usage patterns. In the past, these applications were often implemented in suboptimal ways because Streams did not exist. In real customer applications that use the Streams platform, there has been 10x reductions in servers, storage, and processing time by rebuilding the applications in Streams.

Most successful Streams applications take advantage of one or more of these application types. There are many considerations for determining when to use Streams for your applications. The following sections provide more detail about issues such as application design and performance. There are standard practices that should be considered with all types of Streams applications, such as those in the following list:

- Process data as soon as it enters the enterprise, or as it is generated in the enterprise.
- Process data before it is written to disk (it is okay to use disk as an intermediate step if you plan to change your processes later to be more real time).

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- Streaming analysis should typically come before, or in parallel with, a database or Hadoop infrastructure.
- Streaming analysis should be used in conjunction with your database or Hadoop infrastructure to obtain models and reference data.
- Streaming analysis should keep as much information as possible in memory. Memory is getting big enough to keep large collections of data active across a distributed cluster. Streams provides windowing functions to help manage data in memory.
- Do not use Streams for transactional workload. You can make a Streams application highly reliable, but if you need 100% transactional guarantees, you should use a database. When a database is too slow, you can use Streams, but have to compromise by giving up some level of guarantees or by providing more application logic.
- Do not use Streams when there are multipass algorithms that are highly complex or need to process more data than will fit in memory; use a database or Hadoop instead.
- Use Streams when there are a variety of data types to analyze, such as voice, video, network packets, audio, and waveforms.

3.1 Streams application design

When implementing a business requirement using the IBM InfoSphere Streams platform, the first thing you will need to do is to develop a high-level system design identifying the main components of the system.

As shown in Figure 3-1 on page 70, there are two main components to this design:

1. A logical design identifying the application components to be produced. The logical application design is discussed in the subsequent sections of this chapter.
2. A physical component design identifying the runtime components and hardware platform required to support your application and deliver the level of performance that is required. This physical component design is discussed in Chapter 4, "InfoSphere Streams deployment" on page 139.

At run time, the Streams Scheduler determines how to efficiently segment the application across the hardware hosts. The application should be segmented to produce suitably sized deployable processing elements for the Streams Scheduler to deploy. In 4.5, "Application deployment capabilities" on page 179, we discuss the aspects of appropriate application segmentation.

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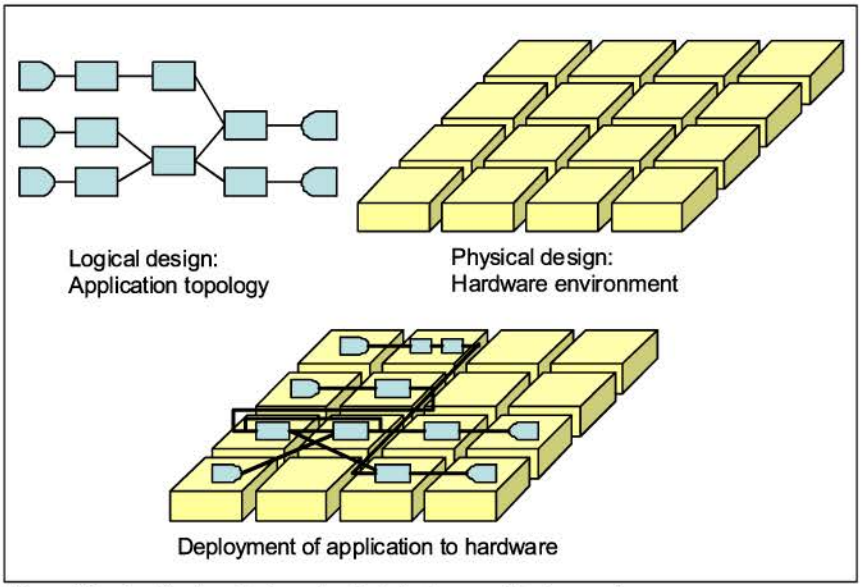


Figure 3-1 Application design, physical design, and deployment

3.1.1 Design aspects

Begin the design of the Streams application by considering the requirements that the system should satisfy and determine if Streams is a natural fit. Next, explore the interfaces of the system, such as what are the inputs that you can use for the application and what are the known outputs that you need to generate. Some of these interfaces are likely to be existing automated systems, so you should be able to determine the technical details of these interfaces. Some of the inputs and outputs may be new, predicted, or unknown, in which case you need to build in the flexibility to handle these less well-defined interfaces. A more detailed discussion of the design of data sources is contained in 3.1.2, "Data sources" on page 72 and outputs are further discussed in 3.1.3, "Output" on page 75.

In cases of complex analytic requirements, it may be necessary to enhance the standard Streams operators by calling out to external software packages or to compile and link the application with existing code. If this is the case, then the design needs to consider the nature of the existing analytics to be utilized. This is discussed further in 3.1.4, "Existing analytics" on page 78.

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As Streams is specifically built for high performance, the success of the application relies on identifying, estimating and forecasting the performance that is required from the application. This is covered in 3.1.5, "Performance requirements" on page 79 and includes a discussion on the volumes of data and the processing speed required.

Figure 3-2 graphically summarizes the steps for this initial stage of application design:

1. Identify the purpose of the proposed system and determine whether or not it aligns with one of the application classes.
2. Define the inputs and outputs required.
3. Identify existing analytics (that is, Streams operators and external libraries) to use.
4. Assess performance, time, and reliability requirements.

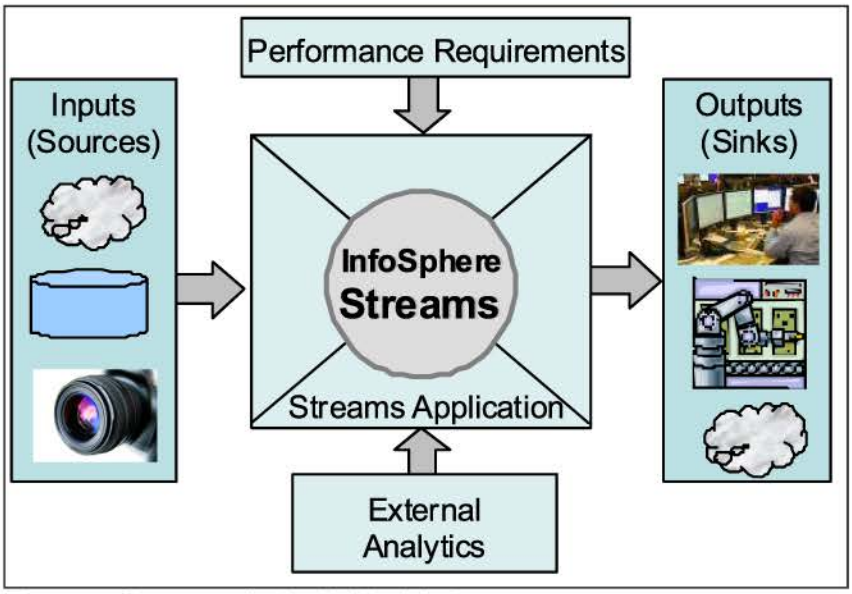


Figure 3-2 Streams application high level design aspects

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3.1.2 Data sources

Identifying and understanding the data sources available to the Streams application is an essential aspect of the design. Some may be well known and well defined, and you may need to ensure that you have flexibility to accommodate additional sources when they become available.

Information content

What is the information content of each source? Regardless of the format and structure of the data source, what are the relevant data items that you expect to extract? Some examples are:

- A feed of video from a traffic camera may allow extraction of information about which vehicles are travelling on a road. The same camera may allow identification of accidents and alert relevant authorities to react.
- Data sources from medical sensors can give specific readings of a patient's bodily condition.
- Feeds of data from web logs (blogs) may allow a quick and appropriate response to the reaction of a business announcement.

Method of access

How can you access the data of each source? A data source can be accessed using a number of flexible, configurable options. As examples, they may be:

- File based, for use when data is being deposited on a locally accessible file system.
- TCP based, so you can access a data stream through a TCP network connection, providing reliable communication of the stream contents from the originator. The Streams Source can be configured to be the server or client side of a TCP connection depending on the requirements.
- UDP based, so you can access a data stream through a UDP network connection. Unlike TCP communications, UDP does not support reliable message transfer, so should only be used in situations where it would be acceptable to lose some of that data to gain additional speed of transfer. The Streams Source can only be the server side of a UDP connection, so the system originating the data needs to connect to the Streams UDP socket.
- Databases, for use when the data resides in a relational database. The Database Toolkit packaged with Streams contains operators for accessing a database.
- Sensors, which may use TCP or UDP for transmitting data, or may use other types of communication methods and libraries to access the sensor data.

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Because Streams applications can use existing libraries to access data or perform operations, sensor data can easily be accommodated.

These options provide different levels of reliability. In some cases, reliability may be essential, in other cases, missing some tuples from an input source may be an acceptable alternative:

- Is the input data being pushed from a remote system? If you miss the opportunity to observe and consume this data, will it be lost?
- Is the data, in some way, buffered or stored so that you can request the contents when you are ready?

Variety of sources

How different is the information content of the various sources?

- You may consume a large number of data sources that all contain the same type of data, such as a huge number of temperature sensors from a manufacturing process.

  Even if the streams are in different formats, it should be possible to convert to a common format, extract the common components, or merge the streams and process the streams in a similar way.

- You may consume a number of different types of data, such as news reports (textual and TV video), stock market feeds, and weather reports to predict stock price movement.

  When the data is of different types, you need more complex comparison, aggregation, and join logic to be able to correlate the streams of data. In this case, it is useful to identify where there are common identities (or keys, in database terminology) that will allow us to relate one stream to another by using, for example, the built-in Join operator.

Structure of data

How well organized is the information that you receive from the data source and how much of the information is likely to be useful? Some data sources are more structured because they are in a concise form and have perhaps been preprocessed, and other data sources are less structured. Although there is not a precise definition, many people in the industry talk about structured and unstructured data:

- Structured data is typically well organized. It is likely to have originated from another computer system, and it will already be processed into a refined form. Therefore, the data received will be known and it is possible that the data will be filtered to provide only those data elements of interest.

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An example of a structured data source is the feed of data that can be acquired from stock markets. The data will be well defined in terms of the attributes that you will receive and the meaning of the data (such as the trading prices for particular stocks) will be well understood.

- Unstructured data is typically less well organized and will need to be identified and extracted from the source form. Discerning information of relevance could require the use of specialized algorithms that need to be integrated with the Streams application.

  An example of an unstructured data source is the wealth of blog data that is published on the Internet. This data is written in free-form text, can be about a wide range of topics, and may be reliable or unreliable sources of information and opinion. As an example, a market research company may be looking for opinions on products in the blogs of consumers, but will have to process a significant volume of data to enable the extraction of the relevant portions.

What is the data format of the information received from the data source? Streams supports two main forms of input data:

- Unicode text as a default: Each line of text is read by the Streams data source and turned into a tuple. A tuple is the Streams term for the individual element of data. Think of a tuple as a row in database terminology, and an object in C++ and Java terminology.
- Binary: As examples, this is the type of data format that comes from video and audio inputs.

These form of input data are translated into the rich type system supported by Streams.

Error checking and optional data

How consistent is the information in the source data stream? In the situation where you have highly structured data, each field in the incoming data will be present, and will have a valid and meaningful value.

However, you may find that frequently the data has values that are omitted from the input, or those values may be invalid. For example, a field that you expect to be a number might be empty, it might include non-numeric values, or it might be a valid number but far larger or smaller than you expected.

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You should identify the level of error checking required and specify what to do when errors or omissions are observed:

- You might need to detect errors in the input stream and either correct or discard these elements.
- Certain attributes in the stream tuples may be optional, and therefore not present in some cases. Appropriate default values should be set in this case.

Control of the data source

In some cases, the data sources may be controllable. that is, they have some mechanism by which you can modify the behavior of the system generating the data. In this case, the results of the Streams application can be used to affect the data produced.

One example of this situation is in the manufacturing use cases where you may control the conditions and ingredients of the production process to fine-tune the results and improve the quality of the product. Another example of data source control is in the use of security cameras, where you may control the direction and zoom of a camera to observe an event of interest.

3.1.3 Output

There will be downstream systems and applications that consume the data output by the Streams application. The Sink operators of the Streams application need to be configured and customized to provide the data to these systems in a format suitable for their use.

When selecting and customizing Sink operators, consider the following items when evaluating how to best interact with systems that consume the output of a Streams application:

- Can the downstream systems read data from files accessible from the Streams run time, such as in a distributed file system? If this is the case, then you can write output files to suitable directories on the Streams file system and the downstream systems can take the data from there. The FileSink operator that is contained in the Streams Standard Toolkit provides an immediate solution for outputting tuple data to a file.

  For high volume data, persistence to disk may be a performance limitation. Therefore, you may need to configure a high speed file system, or send the output using network communication.
- You can output a data stream over a TCP network connection, providing reliable communication of the stream contents to the recipient. The Streams TCPSink can be configured to be the server or client side of a TCP connection depending on the requirements of the receiving system.

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- You can output a data stream over a UDP network connection. Unlike TCP communication, UDP does not support reliable message transfer, so use UDP only in cases where some loss of that data is acceptable to gain additional speed of transfer. The Streams UDPSink can only be the client side of a UDP connection, so the Sink will stream data to a specified IP address and port over a UDP socket.
- Using an ODBC connection, you can insert tuple data into a database table. The ODBCAppend operator that is packaged with the Database Toolkit invokes a SQL INSERT to append data from a stream to a specified table.
- Using an HDFS sink, you can write data into a Hadoop file system for batch analysis by Hadoop that might require more data than can fit within a window.
- There might be another transfer protocol required to send messages over some specific messaging protocol. In this situation, there could be pre-written adapter operators available to support these protocols or you may need to produce a user-defined Sink operator.

You need to identify the format and structure of the data that is required by the external system:

- The required format could be either text based or binary. Having these options means a different configuration will need to be defined in the Streams Sink operator.
- You need to know the required structure of the data, as well as what data items and data types are required.

The nature of the output is determined by the purpose and requirements of the Streams application. In the following sections, we provide some examples of different types of output based on the purpose of the application.

Characterization of metadata

If an application is dealing with high volumes of data, one output may be a description that characterizes aspects of the data stream in a more concise representation. This more concise representation can then be used without having to know the details about the original streams.

For example, when receiving sensor readings from health sensors, you can summarize the individual readings into aggregate values such as the average value, the maximum and minimum, or some statistical measure of the data variation.

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As another example, consider a traffic control system that takes feeds from road traffic cameras. This system will be receiving high volumes of binary video data from the camera and can then output a concise description of relevant events, such as the registration number of any identified vehicle, the location, and the time of the event. The original video data may be needed as an audit trail of the processing, but is not actually required for further analysis processing.

Opportunities

The fast processing that can be achieved with InfoSphere Streams enables you to identify and act on specific situations, thereby gaining a competitive advantage.

A prime example of opportunity identification is that of algorithmic trading in financial markets. Many areas of the financial services industry analyze larger and larger volumes of data to make their trading decisions. The value of a trading decision is highly time sensitive and so faster processing of this data can result in making trades at lower prices, which can result in greater profits.

Novel observations

Combining data from different sources and performing statistical analyses of the correlations allows Streams to uncover patterns and observations in the data streams that might not be evident.

An example of is using radio astronomy to find gamma ray signals among the data from thousands of telescope antennae.

Warnings and alerts

Streams applications can be used to monitor a stream of data and highlight when attributes in the data change state, particularly when an action of some sort should be taken to rectify an error or investigate suspicious activity. An output of warnings and alerts can be generated and fed into downstream systems to prompt action of a suitable nature.

This is the case in the health monitoring example, where Streams can be used to perform analysis of medical sensors, bringing significant changes in status to the attention of appropriate medical practitioners for further examination.

Controls and feedback

The Streams application may be able to directly impact the systems being observed. It can generate outputs that can then be fed as control signals to the automated machines controlling the monitored system, thus providing feedback to the system.

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One example is in the manufacturing use cases where you may control the conditions and ingredients of the production process to fine-tune the results, thereby improving the quality of the product.

Another example of data source control is in the use of security cameras, where you may control the orientation and zoom of a camera to observe an event of interest.

3.1.4 Existing analytics

Using the toolkits provided with InfoSphere Streams, you should be able to develop many useful applications without implementing custom logic in C++ or Java. However, in cases of complex analytic requirements, it might be necessary to extend the standard capabilities by implementing new operators and functions that invoke external software packages. In this case, the design needs to consider the nature of these external packages (for example, libraries) to ensure they are consistent with the requirements and well integrated.

For example, when dealing with unstructured data, you might use specialized analysis systems, such as video processing, audio processing, natural language processing, or language translation systems to analyze the incoming data stream and extract items of relevance. The relevant metadata can then be used as a data stream within the rest of the Streams application.

If the analysis system is packaged as a library, or remote API, you may wrap the API calls that interact with the package in SPL Primitive operators or native functions. Primitive operators may be implemented in either C++ or Java and invoked from your Streams application like any of the operators that are provided with the Streams product. Native functions enable you to package common C++ utilities so that they may be reused in your streams applications.

A related scenario is the case where you are migrating to Streams from a traditional platform. If suitable software packaging and APIs are available, the algorithms implemented using earlier code may be reused by invoking the APIs from Primitive operators and native functions.

You need to consider the implications of the new Streams application on any truly external systems. The Streams application will generate extra load on the system and you should confirm that this does not result in problems.

The design needs to determine what you should do if the external system fails or is unavailable. Compensation actions may be required, such as skipping a section of processing or alerting a human operator of the technical problem.

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3.1.5 Performance requirements

One of the main goals of Streams is to deliver high throughput and low latency computation. To achieve this task, the performance requirements of the system need to be well understood. In this section, we discuss a number of aspects of the performance requirements that should be addressed.

You should determine the expected volumes for each data source, and consider the following measures:

- What is the average throughput over a sustained period of time?
- What is the peak expected throughput in any short period of time?
- What growth in data volumes is anticipated in the future?

Knowing the average and peak throughput, for example, allows you to determine the power and quantity of physical hosts required by your target application. Streams has a low impact on the data path in exchange for the scale up and scale out features it provides as well as the application agility. When sizing an application for Streams, the best possible performance from a hand coded distributed application is a good starting point. Sizing of the physical environment is discussed further in 4.2.2, "Sizing the environment" on page 151.

There are cases when it is not possible to process all data by parallelizing or distributing because the data rates are too high or the required processing is too complex. In those cases, you need to determine an acceptable alternative when the volume of data from a data source exceeds what the system can handle. Some alternatives are:

- You can discard excess data. The Source and associated operators can be designed to act as a throttle, filtering the incoming data to a specific rate. It might also be possible to combine multiple records into aggregates (reducing the number of records processed downstream) or to discard excess tuples, either by a random process of sampling, by identifying tuples of lower potential value, or by shedding the most or least recently received tuple using a threadedPort.
- You can buffer excess data in the expectation that this is a peak load period and as the load declines, the system will be able to process that excess data. Note that using this approach will increase the average latency (time to process each individual entry), as latency will also include the time that a tuple is buffered and waiting to be processed. As such, this approach may be undesirable in an extreme low latency focused system, but many applications are not so sensitive and will still provide better latency than alternative approaches.

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- You can control the throughput of select flows by using the Throttle operator. The Throttle operator is provided in the Standard toolkit and is capable of pacing a stream given a rate specified in tuples per second.

Extreme performance requirements may lead you to segment the application to enable processing of smaller chunks, which may then be deployed to separate hosts and processed in parallel. The impact of sizing and extreme volumes on the application structure is discussed further in 4.5, "Application deployment capabilities" on page 179.

3.2 SPL design patterns

In this section, we present a set of SPL design pattern examples. These examples capture strategies and techniques that Streams developers have used to build SPL applications.

The patterns described here implement a specific capability. Typically, an application will be composed of numerous combinations of patterns, each of which provide a particular and common function. For example, applications may use a Data Parallel pattern (3.2.3, "Data Parallel" on page 90), where each parallel data flow executes an instance of the Enrich Stream pattern (3.2.6, "Enriching streams from a database" on page 107). By adapting these examples to your application, you may reuse standard solutions and thereby reduce the effort required to build common functions.

The design patterns described here showcase both general approaches for processing streaming data, as well as specific coding solutions. For example, the Simple Filter (3.2.1, "Reducing data using a simple filter" on page 82) and Simple Schema Mapper (3.2.2, "Reducing data using a simple schema mapper" on page 86) patterns explain the fundamentals of selecting tuples in a data stream, and a method for converting between stream schema. Almost all SPL applications perform these functions, and usually multiple times. A more elaborate type of filtering is given by the Outlier Detection pattern (3.2.5, "Outlier detection" on page 101). This pattern selects tuples containing data that is numerically distant from other tuples in a stream, and may be adapted to generate alerts for exceptional conditions. The Enrich Stream pattern (3.2.6, "Enriching streams from a database" on page 107) provides a detailed example of how to use operators in the Streams Database Toolkit to enrich a data stream with information from an external database. Other common code solutions, such as how to obtain runtime metrics using the standard Custom operator, or how to implement a Primitive operator that dynamically updates stream subscription properties are described by the Adapting to Observations (3.2.11, "Adapting to observations of runtime metrics" on page 134) and the Updating Import Stream

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Subscriptions patterns (3.2.9, "Updating import stream subscriptions" on page 120), respectively.

In addition to distinguishing patterns by the level of detail described, the pattern examples implement different types of functions. The Processing Multiplexed Stream (3.2.8, "Processing multiplexed streams" on page 116), Simple Filter (3.2.1, "Reducing data using a simple filter" on page 82), and Simple Schema Mapper (3.2.2, "Reducing data using a simple schema mapper" on page 86) patterns perform common transformations on the streaming data. Techniques for improving latency and throughput are addressed by the Data Parallel (3.2.3, "Data Parallel" on page 90) and Data Pipeline (3.2.4, "Data Pipeline" on page 97) patterns. These examples explain methods for exploiting the distributed support provided by Streams to execute operations of the data flow concurrently, and thereby enhance performance. Another mechanism for adjusting application performance is exemplified by the Adapting to Observations (3.2.11, "Adapting to observations of runtime metrics" on page 134) and Tuple Pacer (3.2.7, "Tuple Pacer" on page 111) patterns, which use runtime metrics and processing latency, respectively, to change application behavior. The Updating Import Stream Subscription (3.2.9, "Updating import stream subscriptions" on page 120) and complementary Updating Export Stream Properties (3.2.10, "Updating export stream properties" on page 127) show how to establish stream connections at run time.

The documentation for each design pattern explains how to use and implement the pattern. Additionally, references are provided to related patterns and recommended reading. More specifically, the pattern documentation includes the following subsections:

- When to use: Describes scenarios where the example may be used.
- How to use: Identifies changes to be considered when adapting the pattern example for your application.
- Inputs, Outputs, and Parameters: A short description of each input stream, output stream, and parameter.
- Implementation: Shows how the pattern is implemented. This subsection may include SPL code, as well as implementations of the primitive operators, where relevant.
- Walkthrough: A step-by-step execution of the data flow for the implementation or example code.
- Example: Demonstrates how to invoke the pattern from an SPL application. Example input and output data may also be provided.

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Although the set of example designs presented here are a limited sample of the many patterns that will be used by Streams applications, they should provide a good start for developing your SPL code. Becoming familiar with these patterns will help you learn good practices for building applications for Streams, as well as design patterns that you can use and share.

3.2.1 Reducing data using a simple filter

When you are processing large volumes of data, much of the data may be considered to be irrelevant to your analysis. For example, you might only be interested in data that occurs infrequently, or is represented by a small fraction of the data. This design pattern describes a rudimentary filter for selecting tuples that contain a particular value for an attribute. The following sub-sections further describe the simple filter.

When to use

This pattern is useful for reducing the volume of data consumed by an SPL application. Consider applying this pattern when downstream operators require a subset of the streaming data, and filtering the steam yields a material reduction in latency or system resources consumed.

How to use

Insert one or more filters as far upstream in your application as possible. In general, when processing high volume streams, you should consider filtering the streams to reduce their volumes as soon as possible after they are ingested. This can reduce the total processing workload of the application, allowing a higher volume of throughput, with lower latency and potentially using less hardware. The example design pattern discussed below filters a stream of stock transaction data.

Input ports

Transactions: A full take of the stock transactions.

Output ports

SelectTransactions: Only the transactions containing the selected ticker symbol.

Parameters

$tickerSymbol: The selected ticker symbol (for example, IBM).

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Implementation

The example implementation of the filter selects stock transaction records for a particular ticker symbol. The operator takes as input a set of transaction records, and outputs the transaction records for a particular stock symbol. The stock symbol to select is specified as an input parameter (tickerSymbol) to the operator. This pattern is implemented as a Composite operator called TickerFilter. Given the input stream of transaction data, and a stock ticker symbol to select, the Composite operator invokes a Filter operator, which is provided in the standard toolkit for SPL.

The code for the Composite operator, sample.TickerFilter, is shown in Example 3-1.

Example 3-1 Composite operator TickerFilter

```
type
  TransactionRecord = rstring ticker, rstring date, rstring time,
                      rstring ttype, decimal64 price, decimal64 volume,
                      decimal64 bidprice, decimal64 bidsize,
                      decimal64 askprice, decimal64 asksize;

composite TickerFilter(output SelectTransactions; input Transactions) {
      param
           expression<rstring> $tickerSymbol;
      graph
           stream<TransactionRecord> SelectTransactions = Filter(Transactions) {
                param
                  filter : ticker == $tickerSymbol;
      }
}
```

Figure 3-3 shows the TickerFilter operator.

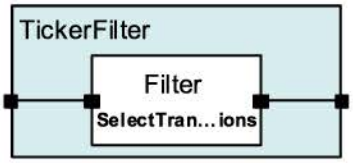


Figure 3-3 TickerFilter

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Example

In Example 3-2, we show how you may invoke the TickerFilter example design pattern. Note that in this example, the ticker symbol to select is specified using a submission time parameter. The value of the tickerSymbol parameter is defined as a key-value pair when you launch the job.

Example 3-2 Invoking the TickerFilter

```
composite SimpleFilterMain {
     param
        // #1 The ticker symbol to select is defined by the tickerSymbol
        // submission time parameter
        expression<rstring> $tickerSymbolValue:
           getSubmissionTimeValue("tickerSymbol");
     graph
        // #2 Read the transaction data from a file
        stream<TransactionRecord> allTickers = FileSource() {
            param
                file : "SmallTradesAndQuotes.csv";
                format : csv;
        }
        // #3 Invoke the TickerFilter operator to filter out all but the
        // specified ticker symbol
        stream<TransactionRecord> selectedTicker = TickerFilter (allTickers) {
            param tickerSymbol : $tickerSymbolValue;
          }
        // #4 Write the filtered stream to a file.
        () as sinkPrefixSink = FileSink(selectedTicker)   {
            param
                file : "FilteredTradesAndQuotes.csv";
        }
}
```

Figure 3-4 shows the TickerFilter design pattern.

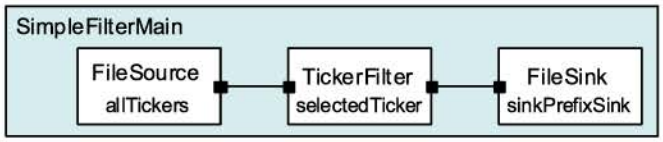


Figure 3-4 TickerFilter design pattern

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Walkthrough

The following steps provide a walkthrough for Example 3-2 on page 84:

1. Obtain the stock symbol to select from the tickerSymbol submission time value. Assign the value of the symbol to the tickerSymbolValue variable.
2. Read the full take of transaction data from the SmallTradesAndQuotes input file, where the records are formatted as comma separated variables. The FileSource operator produces an allTickers stream.
3. For each tuple in the allTickers stream, invoke the TickerFilter operator to filter the input stream. If the transaction record references the input ticker symbol, the TickerFilter operator forwards the transaction record. Otherwise, the transaction record is not forwarded.
4. For each tuple in the selectedTicker stream, invoke the FileSink to output the selected transaction record. Given an input file `SmallTradesAndQuotes`, where the first few records are as follows:

   ```
   "ASA","27-DEC-2005","14:30:07.458","Quote",0,0,53.13,2,53.21,1
   "AVZ","27-DEC-2005","14:30:07.458","Quote",0,0,15.62,1,15.7,100
   "AYI","27-DEC-2005","14:30:07.458","Quote",0,0,32.38,1,32.49,13
   "BGG","27-DEC-2005","14:30:07.520","Quote",0,0,39.79,2,39.81,13
   "IBM","27-DEC-2005","14:30:07.521","Trade",83.48,74200,0,0,0
   "GSL","27-DEC-2005","14:30:07.582","Quote",0,0,43.65,1,43.71,1
   "JNS","27-DEC-2005","14:30:07.582","Quote",0,0,18.84,1,18.86,38
   "DLB","27-DEC-2005","14:30:07.585","Quote",0,0,16.84,23,16.95,1
   ```

   The SimpleFilterMain started with a tickerSymbol of IBM yields an output that includes the following records:

   ```
   "IBM","27-DEC-2005","14:30:07.521","Trade",83.48,74200,0,0,0
   "IBM","27-DEC-2005","14:30:08.117","Quote",0,0,80.43,18,83.49,10
   "IBM","27-DEC-2005","14:30:13.283","Quote",0,0,83.43,18,83.46,10
   "IBM","27-DEC-2005","14:30:13.518","Trade",83.45,200,0,0,0
   "IBM","27-DEC-2005","14:30:13.718","Quote",0,0,83.42,4,83.46,10
   "IBM","27-DEC-2005","14:30:14.731","Quote",0,0,83.42,4,83.45,1
   "IBM","27-DEC-2005","14:30:15.751","Quote",0,0,81.42,4,83.45,3
   ```

Note that the output file represents the results of filtering thousands of transaction records, where only the first one (that is, `"IBM","27-DEC-2005","14:30:07.521",...`) is listed in the extract of the input file previously shown.

Refer to 3.2.2, "Reducing data using a simple schema mapper" on page 86, where we provide a design pattern example that describes an alternative for reducing data volume.

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3.2.2 Reducing data using a simple schema mapper

A simple Streams application may be used to map between stream schema. Streams applications commonly map between schema for the purpose of selecting only relevant attributes, or translating between different schema. This design pattern addresses the former scenario and describes how to use SPL to reduce a schema.

When to use

This pattern is useful when the input data contains attributes that are not used by downstream operators. In this case, excluding unused attributes at the appropriate point in the data flow reduces the data volume. Related scenarios include combining attributes by mapping one or more input types to fewer output types.

How to use

This pattern may be used as a stand-alone utility, where it would ingest an input file and produce an output file with fewer attributes. More commonly, this pattern may be embedded in an application whenever you need to translate one schema to another.

Input ports

BigSchema: The stream whose schema is to be reduced.

Output ports

SmallSchema: The output stream with fewer schema attributes.

Parameters

SmallSchemaType: The schema of the output stream.

Implementation

This pattern is implemented as a Composite operator that uses a Functor to select a subset of the attributes in the input stream to produce an output stream with fewer attributes. Without additional parameterization, the Functor operator will match like named attributes between the input and output streams. The composite (SimpleSchemaReducer) is type generic, and assumes that the schema for the input and output streams are defined by the application that invokes this Composite operator. To provide ongoing feedback to the user, the Functor outputs a progress message for every 1000 input records processed.

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The code for the Composite operator sample SimpleSchemaReducer is shown in Example 3-3.

Example 3-3 Composite operator SimpleSchemaReducer

```
composite SimpleSchemaReducer(output SmallSchema; input BigSchema) {
      param
        // The schema of the output stream.  Set this parameter to the name
        // of the SPL type that defines the output schema.
        type $SmallSchemaType;
      graph
        stream<TransactionRecordOutput> SmallSchema = Functor(BigSchema) {
            logic
               // Since this is implemented as a utility, provide the user with
               // periodic feedback on progress, and finally, the total number of
               // records processed.
               state : {
                 mutable int32 i = 0;
               }
               onTuple BigSchema : {
                   if ((++i % 1000) == 0) {
                      println("processing record#: " + (rstring)i);
                   }
               }
               onPunct BigSchema: {
                  println ("total records: " + (rstring)i);
               }
      }
```

Figure 3-5 shows the SimpleSchemaReducer.

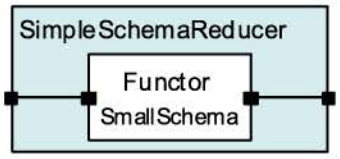


Figure 3-5 SimpleSchemaReducer

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Walkthrough

The following steps provide a walkthrough for Example 3-3 on page 87.

1. It is assumed that the SimpleSchemaReducer Composite operator is being invoked from an application. In this case, the invoking application is feeding the SimpleSchemaReducer with stream BigSchema and is consuming the resulting SmallSchema stream. The SimpleSchemaReducer is parameterized with the TransactionRecordOutput type, which is the reduced schema used by the output stream.
2. For each tuple received on the BigSchema stream, the Functor produces a tuple with just those attributes of the input stream that are also defined in the schema of the output stream. Note that because no attributes are assigned in the output clause, the Functor implicitly assigns the input attributes to the output attributes with the same name.
3. For each 1000 tuples, the Functor provides a progress indicator to the user and reports the total number of tuples that have been processed.

Example

The example implementation of the schema mapper simplifies the schema used by the Vwap sample application. (The Vwap application is packaged with the InfoSphere Streams product in the `samples/spl/application/Vwap` directory). In particular, the TransactionDataSchemaMapper example composite reduces the 29 attributes (that is, columns) contained in the input stream to nine attributes that are used by one of the other design patterns. This particular example is implemented as a utility, which takes the TradesAndQuotes file as input (which contains 29 attributes) and produces SmallTradesAndQuotes, a smaller file that contains just nine attributes. The example code for the SimpleSchemaMapper is shown in Example 3-4. For more information, see "SPL schema" in *Streams SPL Language Reference*.

Example 3-4 shows an example TransactionDataSchemaMapper Composite operator.

Example 3-4 TransactionDataSchemaMapper

```
composite TransactionDataSchemaMapper
   type
   // Input record of transaction data with 29 attributes
   TransactionRecordInput
     = rstring ticker,rstring date, rstring time, int32 gmtOffset,
       rstring ttype, rstring exCntrbID, decimal64 price,
       decimal64 volume, decimal64 vwap, rstring buyerID,
       decimal64 bidprice, decimal64 bidsize, int32 numbuyers,
       rstring sellerID, decimal64 askprice, decimal64 asksize,
       int32 numsellers, rstring qualifiers, int32 seqno,
```


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```
    rstring exchtime, decimal64 blockTrd, decimal64 floorTrd,
    decimal64 PEratio, decimal64 yield, decimal64 newprice,
    decimal64 newvol, int32 newseqno, decimal64 bidimpvol,
    decimal64 askimpcol, decimal64 impvol;

// Output record of transaction data with reduced schema, containing
// only 9 attributes
TransactionRecordOutput
  = rstring ticker, rstring date, rstring time,
    rstring ttype, decimal64 price, decimal64 volume,
    decimal64 bidprice, decimal64 bidsize, decimal64 askprice,
    decimal64 asksize;

graph
  // #1 Read full take of transaction data from comma separated input file
  stream<TransactionRecordInput> TradeQuote = FileSource() {
   param
     file : "TradesAndQuotes.csv";
     format : csv;
   }

   // #2 Map large record used by TradeQuote to reduced TransactionRecordOutput
   // schema.
   stream<TransactionRecordOutput> TradeQuoteSmall =
      SimpleSchemaReducer(TradeQuote) {
        param SmallSchemaType : TransactionRecordOutput;
   }

   // #3 Output reduced transaction to file, format as comma separated variables
   () as sinkPrefixSink = FileSink(TradeQuoteSmall)   {
         param
             file : "SmallTradesAndQuotes.csv";
             format : csv;
   }
}
```


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Figure 3-6 shows the TransactionDataSchemaMapper.

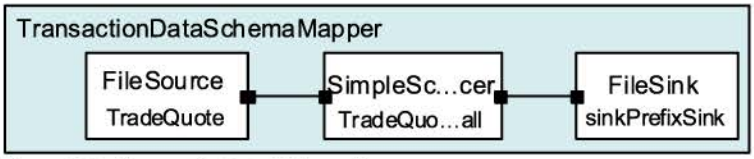


Figure 3-6 TransactionDataSchemaMapper

The `TradesAndQuotes.csv` input file contains records such as:

```
ASA,27-DEC-2005,14:30:07.458,-5,Quote,,,,,53.13,2,,,53.21,1,,R[PRC],,,,,,,,,,,
AVZ,27-DEC-2005,14:30:07.458,-5,Quote,,,,,15.62,1,,,15.7,100,,OQ[PRC],,,,,,,,,,,
AYI,27-DEC-2005,14:30:07.458,-5,Quote,,,,,32.38,1,,,32.49,13,,R[PRC],,,,,,,,,,,
BGG,27-DEC-2005,14:30:07.520,-5,Quote,,,,,39.79,2,,,39.81,13,,R[PRC],,,,,,,,,,,
IBM,27-DEC-2005,14:30:07.521,-5,Trade,,83.48,74200,83.4800,,,,,,,,Open|High|Low[GEN],46
19,14:30:07,1,,,,,,,,
GSL,27-DEC-2005,14:30:07.582,-5,Quote,,,,,43.65,1,,,43.71,1,,R[PRC],,,,,,,,,,,
JNS,27-DEC-2005,14:30:07.582,-5,Quote,,,,,18.84,1,,,18.86,38,,R[PRC],,,,,,,,,,,
DLB,27-DEC-2005,14:30:07.585,-5,Quote,,,,,16.84,23,,,16.95,1,,OQ[PRC],,,,,,,,,,,
```

The TransactionDataSchemaMapper utility outputs the same records to SmallTradeAndQuote, but with only nine of the 29 columns from the input file:

```
"ASA","27-DEC-2005","14:30:07.458","Quote",0,0,53.13,2,53.21,1
"AVZ","27-DEC-2005","14:30:07.458","Quote",0,0,15.62,1,15.7,100
"AYI","27-DEC-2005","14:30:07.458","Quote",0,0,32.38,1,32.49,13
"BGG","27-DEC-2005","14:30:07.520","Quote",0,0,39.79,2,39.81,13
"IBM","27-DEC-2005","14:30:07.521","Trade",83.48,74200,0,0,0,0
"GSL","27-DEC-2005","14:30:07.582","Quote",0,0,43.65,1,43.71,1
"JNS","27-DEC-2005","14:30:07.582","Quote",0,0,18.84,1,18.86,38
"DLB","27-DEC-2005","14:30:07.585","Quote",0,0,16.84,23,16.95,1
```

Refer to 3.2.1, “Reducing data using a simple filter” on page 82; that design pattern example describes an alternative for reducing data volume.

3.2.3 Data Parallel

This design pattern partitions a data stream into multiple separate (or parallel) data flows. The operators in each of the parallel data flows implement the same logic. This pattern assumes that each of the parallel data flows execute in a separate thread. When assigned to different processors, the parallel data flows may execute simultaneously, thereby yielding a potential improvement in both latency and throughput.

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To illustrate this pattern, we implement a simple application that aggregates revenue from a stream of food orders for a chain of restaurants.

When to use

Consider using this pattern when the inbound data stream can be partitioned into multiple outbound streams and subsequently recombined to yield a single outbound stream. To realize throughput improvements, the systems on which this application is run should have enough processors to execute the parallel data flows simultaneously.

Note that this pattern does not provide a mechanism for preserving the tuple order. As a result, this pattern should be used only when tuple order need not be preserved. Alternatively, the pattern may be extended to include an operator to add a sequence number prior to splitting and another operator to reorder the tuples subsequent to merging the parallel streams.

Additional considerations should be given to handling cases where ordering of tuples may be discontinuous as a result of tuples being dropped due to filtering operators or congestion on a stream.

How to use

To adapt the basic fan-out, fan-in structure of this pattern to your application, consider the following items:

- Identify a key in the inbound tuple attributes that may be used to partition the data streams.
- Count or estimate the unique values of this key. Depending on the data stream, you may want to use a separate operator for computing the distribution of key values.
- Count or estimate the number of processors available on the cluster on which the data parallel pattern will execute.
- Determine the number of parallel paths by determining how the operators in each path would be placed on processes.
- Define a mapping between keys and ports (output streams) that balances the volume of tuple data across the parallel paths.

Note that this pattern may be further abstracted by using a separate composite to implement the parallel data flows.

Input ports

Orders: Food orders from all restaurants.

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Output ports

RevenueTot: Snapshot of aggregate revenue for food orders.

Parameters

$snapshotPeriod: expression<int32> period (in seconds) for computing revenue snapshot.

Implementation

Implementations of this pattern are characterized by complementary Split and Union operators. The upstream Split operator demultiplexes the tuples in the inbound data stream by assigning each tuple to one of the operator's output ports. The assignment may be determined by a function on a tuple attribute that maps a value to the operator's output port number, or by a mapping table loaded by the operator. The Union operator, which is positioned downstream of the Split, multiplexes the partitioned data flow, yielding a single outbound stream.

Between the Split and Union operators are parallel sub-graphs that perform identical processing on the partitioned inbound data. Instead of a Union operator, patterns of this type may employ a Barrier or a Join to synchronize and combine the results of the parallel data flows.

This example pattern computes a periodic snapshot of revenue for a large restaurant chain. For each item on the menu, a tuple is created whenever a customer orders the product (burger, fries, drink, or dessert) from the menu. Because there are potentially thousands of franchises, and millions of orders per day, we can improve throughput by parallelizing the work of aggregating revenue. For this example, the ParallelAggregator composite operator contains the code that performs the parallel computation. Looking inside this composite, the Split demultiplexes the inbound tuples by mapping the value of the enumeration representing the menu item (that is, category) to an output port. Each of the streams output by the Split is consumed by a separate instance of a ComputeRevenueSnapshot operator. This operator is intended to serve as a placeholder for the computation performed on each parallel data flow. The Union operator multiplexes the tuples produced by each of the ComputeRevenueSnapshot operators and routes the tuples to an Aggregator, which computes a total revenue for each menu item over period specified by the $snapshotPeriod parameter.

The ComputeRevenueSnapshot consists of a single Aggregate operator, which sums the cost of the menu item at a frequency specified by the submission time $period parameter. For a commercial application, this composite may contain a large sub graph, each of which is executed in parallel.

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The code for ComputeRevenueSnapshot and the types used by this example are shown in Example 3-5.

Example 3-5 ComputeRevenueSnapshot

```
type OrderCategoryT = enum {burgers, fries, drinks, deserts, other};
type OrderRecordT = OrderCategoryT category, int64 cost;
type RevenueRecordT = int64 totalCost;

composite ComputeRevenueSnapshot(output RevenueSnapshot; input Orders) {
       param
         // The period, in seconds, for computing a revenue snapshot
         expression<int32> $period;
       graph
        // Put parallel data computation here.
        // Aggregate cost across orders received during specified period
        stream<RevenueRecordT> RevenueSnapshot = Aggregate(Orders) {
            window
                Orders: tumbling, time($period);
            output
                RevenueSnapshot : time = getTimestamp(),
                                  totalCost = Sum(cost);
        }
}
```

The ParallelAggregator Composite operator is shown in Example 3-6.

Example 3-6 ParallelAggregator Composite operator

```
composite ParallelAggregator(output RevenueTot; input Orders) {
       param
         // #1 Period for computing revenue snapshots.
         expression<int32> $snapshotPeriod;
       graph
          (stream<OrderRecordT> OrderBurgers;
           stream<OrderRecordT> OrderFries;
           stream<OrderRecordT> OrderDrinks;
           stream<OrderRecordT> OrderDeserts;
           stream<OrderRecordT> OrderOther) = Split(Orders) {
            param
             index : (int64)category;
        }
        stream<RevenueRecordT> RevenueBurgers = ComputeRevenueSnapshot(OrderBurgers)
           {
               param period : $snapshotPeriod;
        }
```


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```
        stream<RevenueRecordT> RevenueFries = ComputeRevenueSnapshot(OrderFries) {
               param period : $snapshotPeriod;
        }
        stream<RevenueRecordT> RevenueDrinks = ComputeRevenueSnapshot(OrderDrinks) {
               param period : $snapshotPeriod;
        }
        stream<RevenueRecordT> RevenueDeserts = ComputeRevenueSnapshot(OrderDeserts)
           {
               param period : $snapshotPeriod;
        }
        stream<RevenueRecordT> RevenueOther = ComputeRevenueSnapshot(OrderOther) {
               param period : $snapshotPeriod;
        }
        stream<RevenueRecordT> RevenueUnion = Union(RevenueBurgers;RevenueFries;
                                                    RevenueDrinks;RevenueDeserts;
                                                    RevenueOther) {
        }
        stream<RevenueRecordT> RevenueTot = Aggregate(RevenueUnion) {
            window
                RevenueUnion:  tumbling, time($snapshotPeriod);
            output
                RevenueTot: totalCost = Sum(totalCost);
        }
}
```

Figure 3-7 shows the ParallelAggregator.

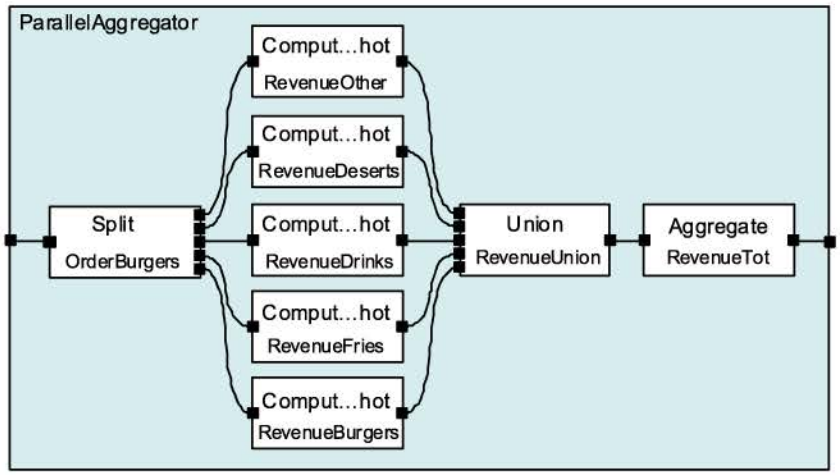


Figure 3-7 ParallelAggregator

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Walkthrough

The following steps provide a walkthrough for Example 3-6 on page 93:

1. When invoked, the ParallelAggregator is initialized with the value of the $snapshotPeriod parameter. This parameter specifies the number of seconds to wait before computing another snapshot of the revenue.
2. For each tuple received by the ParallelAggregator, the value of the category attribute maps to the index of the output port on which the Split operator will route the tuple.
3. The tuple routed by the Split is passed to the instance of ComputeRevenueSnapshot operator that handles the category. The ComputeRevenueSnapshot is also initialized with the $snapshotPeriod.
4. The output from the ComputeRevenueSnapshot operator is re-multiplexed onto the RevenueUnion stream output by the Union operator.
5. A total for the revenue snapshots for each order category is computed periodically, as specified by the $snapshotPeriod parameter. Tuples containing the sum of revenue snapshots is output to the RevenueTot stream.

Example

The code listing shown in Example 3-7 shows a main composite that invokes the ParallelAggregator. The Beacon operator generates a value from 1 to 5 to represent the category of the food order (burgers, fries, and so on), and value from 1 - 6 to represent the cost. Each generated order is processed by the ParallelAggregator, and the results are exported using stream with the RevenueSnapshots ID.

Example 3-7 ParallelAggregator

```
composite ParallelDataFlowMain {
    graph
       // Use a beacon to generate sample orders for food.
            stream<OrderRecordT> Orders = Beacon() {
                   param period : 0.5;
                   output
                      Orders : category = (OrderCategoryT) (int32)(random() * 5.0),
                               cost = (int64)((random() * 5.0) + 1.0);
       }
       stream<RevenueRecordT> RevenueSnapshots = ParallelAggregator(Orders) {
              // Produce a snapshot for orders every 36 seconds.  In practice, the
              // period would be greater - hours or days.  36 seconds is useful for a
              // demo.
              param snapshotPeriod : 36;
       }

       () as eRevenueSnapshots = Export(RevenueSnapshots) {
```


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```
        param streamId : "RevenueSnapshots";
    }
}
```

Figure 3-8 shows a graph of the ParallelDataFlowMain.

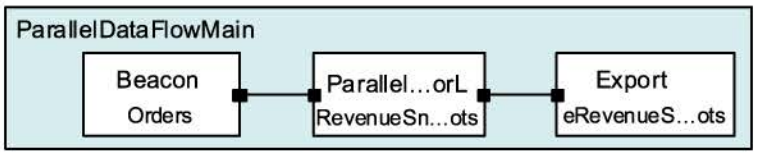


Figure 3-8 TransactionDataSchemaMapper

The following records show an extract of the input data generated by the Beacon in the main composite:

- other,1
- burgers,1
- burgers,2
- drinks,5
- other,4
- drinks,5
- other,5
- deserts,2
- drinks,2
- burgers,2
- drinks,4

A sampling of the tuples captured from the RevenueSnapshots stream is shown below. Each tuple represents a snapshot of the aggregated revenue.

```
(1305817600,400524000,0),832
(1305817636,402356000,0),860
(1305817672,403847000,0),797
(1305817708,405234000,0),810
(1305817744,406678000,0),905
(1305817780,408331000,0),841
```

The left column displays the SPL time stamp of the snapshot (in parenthesis), and the right most column contains the revenue collected during that period from all the chain restaurants. From left to right, the time stamp is encoded as seconds since the epoch, nanoseconds, and a machine identifier.

Refer to 3.2.4, “Data Pipeline” on page 97, where we have a design pattern that describes an alternative approach to executing Streams operators in parallel.

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3.2.4 Data Pipeline

This design pattern describes how to speed up processing by arranging a sequence of operators in a pipeline. The processing improvement is realized by positioning the operators in a linear sequence, or pipeline, so that each operator may execute in a separate thread. By assigning the operator's threads to different processors or hosts, consecutive tuples may be processed concurrently.

When to use

The Pipeline design pattern is useful for increasing throughput. The important considerations include:

- Tuples should not be dependent on one another, that is, the data values in one tuple should not be derived from another. This enables operations on different tuples to be executed concurrently.
- The target environment should provide multiple processors or hosts on which the multiple threads may be assigned.
- The distribution of execution time across the operators should be relatively even. Otherwise, if the latencies are not balanced, a slower operator might interfere with the smooth flow through the pipeline, and thereby limit the degree of concurrent execution.

How to use

The typical uses of the pipeline graph design pattern include the progressive (and concurrent) enrichment of tuple data as the tuple moves down the pipeline. To achieve the benefits of concurrency, the environment should enable the placement of operators on different processors or hosts. In the case that multiple operators are fused in the same processing element (PE), and are connected through threaded ports, ensure that the PE runs on a host with a sufficient number of processors to achieve an acceptable degree of concurrency across the fused operators. If the application consists of multiple PEs, consider how the operators should be assigned to different hosts. Typically, the pipeline is embedded in a Composite operator and provides one input and one output port. Because the pipeline is processing the series of tuples in order, an implementation will respect a FIFO discipline.

Input ports

In: The data stream input to the pipeline.

Output ports

Out: The data stream output by the pipeline.

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Implementation

The Pipeline pattern is implemented by a linear data flow of Functors. Note that the input port for each operator in the pattern is threaded. The threadedPort configuration declares that each operator executes on a separate thread. This thread dequeues the inbound tuple and invokes the operator's process method. This enables each operator, even if used in the same processing element, to execute concurrently. The configuration of the threaded port in this implementation specifies that the port will use a queue depth of 1 (the rightmost parameter), and will block when the queue is full (indicated by the Sys.Wait parameter). The first Functor in the pipeline uses the getPricefunction to retrieve the price for the order's part number. Given the price, the second operator verifies the customer has the credit required to purchase the part at the specified price. If the creditOK function returns true, implying that the customer has sufficient credit, this operator sets the orderOK attribute to true, and forwards the tuple. The last operator in the pipeline checks the inventory for the part number and sets the orderOK to false if the inventory is short. The implementations of the functions that get the price and inventory and run the credit check are not shown here. In practice, we would expect that various optimizations would be used, such as caching prices, and checking inventory only if the credit check succeeds. To simplify the example, we do not use these obvious optimizations.

The code for the Composite operator com.ibm.designpatterns.pipelineflow.Pipeline is shown in Example 3-8.

Example 3-8 Composite operator for Pipeline

```
composite Pipeline(output stream<OrderRecordT> Out; input stream<OrderRecordT> In) {
  graph
    // Given a part number, retrieve and add the price to the
    // order record
    stream<OrderRecordT> Order1 = Functor(In) {
      output
        Order1 : price = getPrice(In.partNum);
      config
        threadedPort : queue(In, Sys.Wait, 1);
    }
    // Given the price and quantity, check the customer's credit. Set orderOK to
    // false, if the customer credit is not sufficient for this order.
    stream<OrderRecordT> Order2 = Functor(Order1) {
      output
       Order2 : orderOK = creditOK(Order1.custNum, (float32)Order1.quantity *
         Order1.price);
      config
        threadedPort : queue(Order1, Sys.Wait, 1);
    }
```


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```
    // Given part number and quantity, verify that the inventory is sufficient to
    //satisfy the order.
    stream<OrderRecordT> Out = Functor(Order2) {
      output
        Out : orderOK = ((float32)Order2.quantity <= getInventory(Order2.partNum));
      config
        threadedPort : queue(Order2, Sys.Wait, 1);
    }
}
```

Figure 3-9 shows a graph of the Pipeline design pattern.

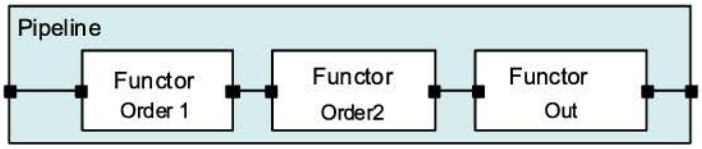


Figure 3-9 Pipeline design pattern

Walkthrough

The following steps provide a walkthrough for Example 3-8 on page 98.

1. Tuple-1, containing a customer order, is received by the first Functor in the pipeline on input stream In. After retrieving the price for the input part number, this Functor forwards the tuple on output stream RawOrderRecords.
2. The second Functor receives Tuple-1 on its threaded input port and runs a credit check to validate that the customer can afford the part.
3. Because the second Functor uses a threaded input port, the first Functor in the pipeline can process the Tuple-2 without waiting for the second Functor to complete. While the second Functor runs the credit check for the customer reference by Tuple-1, the first Functor obtains the price for the part number specified in Tuple-2.
4. When the second Functor completes the credit check for Tuple-1, it forwards the tuple on stream Order2 to the third and last Functor in the pipeline. While the third Functor verifies the inventory for Tuple-1 while running on a thread used to dequeue that tuple, the first and second operators in the pipeline may be concurrently processing the next tuples on the inbound stream (Tuple-3 and Tuple-2, respectively).

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Example

The following main composite invokes the operator that implements the pipeline. The pipeline is used to gather data to complete a customer order. The input consists of tuples that contain a part number and a quantity. The Pipeline operator enriches the input data with pricing information and sets the orderOK Boolean to true if the order can be processed (for example, the customer has the required credit).

A graph of the main composite is shown in Example 3-9. The Composite operator that produces the OrderRecords stream implements the Pipeline design pattern. This stream is exported by the main composite. It is assumed that another SPL application may consume this output and further process the customer order.

Example 3-9 Composite Pipeline main

```
// Represents a customer number.
type CustNumberT = enum {c9999, c9998, c9997, c9996};
// Represents the part that the customer is ordering
type PartNumberT = enum {p001, p002, p003, p004, p005};
// Represents an order for a part submitted by a customer.
type CustomerOrderT = CustNumberT custNum, PartNumberT partNum, int32 quantity;
// Represents an order processed by the fullment system.
// The orderOK boolean indicates whether the order has been verified
// (e.g. credit check and inventory are OK).
type OrderRecordT = CustomerOrderT,tuple<float32 price, boolean orderOK>;

composite PipelineMain {
  graph
    // The Beacon operator emulates a stream of customer orders
    // Each order is initialized with a part number and quantity.
    stream<CustomerOrderT> Orders = Beacon() {
      param period : 0.5;
      output Orders : custNum = (CustNumberT) ((int32)(random() * 3.0)),
                      partNum = (PartNumberT) ((int32)(random() * 4.0)),
                      quantity = (int32) (random() * 100.0);
      }
      // Transform a customer order to a OrderRecord and assign default
      // values for the fields required to process the order, such as the
      // current price and the orderOK boolean.
      stream<OrderRecordT> RawOrderRecords = Functor(Orders) {
        output RawOrderRecords : price = -1.0w, orderOK = false;
      }
      // The Pipeline gathers additional the information required to
      // process the orders.
```


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```
    stream<OrderRecordT> OrderRecords = Pipeline(RawOrderRecords) {
    }
    // Export the order records for additional processing.
    stream<OrderRecordT> eOrderRecords = Export(OrderRecords) {
   }
}
```

Figure 3-10 shows a graph of the Pipeline design pattern.

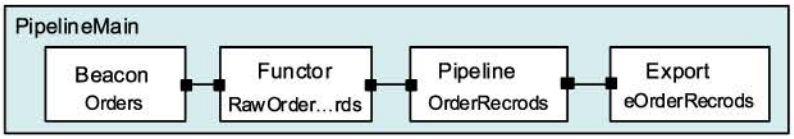


Figure 3-10 PipelineMain

Refer to 3.2.3, "Data Parallel" on page 90, which describes a different methodology for parallelizing execution.

3.2.5 Outlier detection

This design pattern illustrates an operator that monitors a data stream and detects "deviant" data. Real world scenarios that may employ outlier detection include monitors on health metrics where data outliers may imply a critical condition, or stock transactions where high or low prices may inform buy or sell decisions. In this pattern, the operator analyzes the input data to establish a normal range for the stream of data. Those tuples containing the values outside the normal range are considered outliers and are forwarded for further processing.

When to use

Use this pattern whenever the data values conform to a normal distribution, and a standard deviation provides an appropriate method for identifying outliers. This pattern is also useful in scenarios where you need to reduce the data volume. When used to filter tuples consumed by downstream operators, consider positioning this pattern upstream in the application.

How to use

Embed this pattern in Streams applications to generate alerts given exceptional data, or to identify outliers or statistically significant results.

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Input ports

AllData: The complete take of all tuples.

Output ports

Outliers: The tuples with relatively high or low data values.

Parameters

$numStandardDeviations: expression<float64>, which is the number of standard deviations used to identify outliers.

Implementation

Given an input stream consisting of tuples with non-negative data values, this operator forwards only those tuples that are considered outliers. Outliers are identified by computing the distance of a data value from a mean. The mean is aggregated over a window of tuples, and the distance is defined by a number of standard deviations. In the OutlierIdentifier operator, the mean and standard deviation are computed by the Aggregate operator, which uses a window of tuples. Using the mean and standard deviation provided by the Aggregrate, the Join operator forwards a tuple received on the AllData stream only if the data value is a specified number of standard deviations distant from the mean. The isOutlier function, invoked as part of the join condition, computes this distance and returns true if the data value is an outlier. This definition of the function and the code for Composite operator OutlierIdentifier is shown in Example 3-10.

Example 3-10 Composite operator OutlierIdentifier

```
composite OutlierIdentifier(output stream<OutlierStreamT> Outliers; input
   stream<DataStreamT> AllData){
       param expression<float64> $numStandardDeviations;
       type RunningStatsT = SourceIdT sourceId, float64 average, float64 standardDev;

       graph
         stream<RunningStatsT> RunningStats = Aggregate(AllData) {
            window
                AllData : partitioned, tumbling, count(100);
            param
                partitionBy: AllData.sourceId;
            output
                RunningStats :
                    sourceId = Any(AllData.sourceId),
                    average = Average(AllData.value),
                    standardDev = SampleStdDev(AllData.value);
      }
```


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```
    stream <OutlierStreamT> Outliers as O = Join (AllData as I1; RunningStats as
       I2) {
          window
              I1: sliding, count(0);
              I2: partitioned, sliding, count(1);
          param
              match : I1.sourceId == I2.sourceId
                      && isOutlier(I1.value, I2.average, I2.standardDev,
                         $numStandardDeviations);
              partitionByRHS : I2.sourceId;
          output
              O: sourceId = I1.sourceId,
                 value = I1.value,
                 average = I2.average,
                 standardDev = I2.standardDev;
    }
}
```

The Composite operator OutlierIdentifier is shown in Figure 3-11:

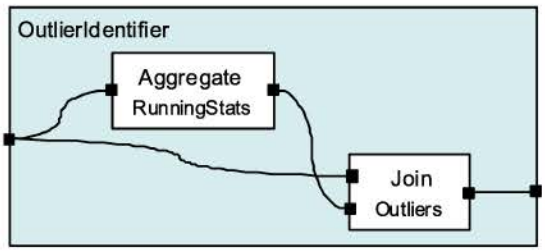


Figure 3-11 OutlierIdentifier

Walkthrough

The following steps provide a walkthrough for Example 3-10 on page 102:

1. Invoke the OutlierIdentifier Composite operator with the number of standard deviations used to identify outlying data values.
2. Forward each tuple received on the AllData stream to the Aggregrate and Join operators. The Aggregate operator derives the statistics used to identify outliers, and Join operator uses these statistics, if available, to evaluate each tuple on the AllData stream and forwards only those tuples that are statistical outliers. The following steps provide more detail about the operation of the Aggregrate and the Join.

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3. The Aggregate operator collects each tuple in a sub-window partitioned by the sourceId attribute. When the hundredth tuple is collected for a particular sourceId, the Aggregrate computes the average and standard deviation for tuples in that window and forwards a tuple containing these statistics on the RunningStats stream to the Join operator.
4. The Join discards the tuples received on AllData stream, until a tuple containing aggregrate statistics with a corresponding sourceId is received from the Aggregate operator on its right port, I2. This may be considered a initialization phase, or "warm-up" period, for the OutlierIdentifier.
5. When the Join operator receives the tuple containing the aggregate statistics on port I2, it caches the tuple in a sub-window partitioned by the sourceId.
6. The next tuple with the same sourceId received by the Join operator on the AllData stream is matched with corresponding tuple received on port I2. If the sourceIds match, and the isOutliers function returns true, the operator's join condition is satisfied, and a tuple representing an outlying data value is output by the Composite operator on the Outliers stream. The tuple cached in the sub-window for port I2 is not evicted until another tuple is received for that sourceId from the Aggregate operator.

Example

The following code provides an example of how to invoke the OutlierIdentifier Composite operator. The Beacon and Functor are used together to generate data tuples with a value field initialized to a random floating point number between 0 and 100, and a sourceId set to one of five enumerated values. To serve this example, the Functor is used to spread the data values and accentuate the top and bottom of the range, and thereby generate more outliers. The output from the Functor, the SpreadDatastream, is fed to the OutlierIdentifier. The resulting outliers, which consist of tuples where the data values exceeds two standard deviations, are captured in the `Outliers.Result.txt` file by one of the FileSinks. The other FileSink records the full take of data fed to the OutlierIdentifier in the `Outliers.AllData.txt` file.

The isOutlier function invoked by the OutlierIdentifier is shown in Example 3-11. This function returns true if a data value exceeds a distance from an average, and false otherwise.

Example 3-11 Outlier function

```
type SourceIdT = enum {A, B, C, D, E};
type DataStreamT = SourceIdT sourceId, float64 value;
type OutlierStreamT = DataStreamT, tuple<float64 average, float64 standardDev>

// Returns true if the input value is an outlier, and false otherwise.
// value - the input value
// avg - the average of the sample
```


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```
// sigma - the standard deviation of the sample
// outlierFactor - the number of standard deviations
boolean isOutlier(float64 value, float64 avg, float64 sigma, float64 outlierFactor) {
  return (value > avg + outlierFactor * sigma) || (value < avg - outlierFactor *      sigma);
}

composite OutlierIdentifierMain {
       graph
         stream<DataStreamT> InputData = Beacon() {
              param period : 0.2;
              output InputData : value = (random()*10.0),
                                 sourceId = (SourceIdT)((int32)(random() * 5.0));
         }

         stream<DataStreamT> SpreadData = Functor(InputData) {
              logic state : {
                 mutable float64 extendedValue;
              }
              onTuple InputData : {
                       mutable float64 randomValue = random();
                       if (randomValue > 0.89) {
                              extendedValue = value * random() * 10.0;
                       } else if (randomValue < 0.19) {
                              extendedValue = value * random() * 0.1;
                       } else {
                              extendedValue = value;
                       }
              }
              output SpreadData : value = extendedValue;
     }

         stream<OutlierStreamT> Outliers = OutlierIdentifier(SpreadData) {
             param numStandardDeviations : 2;
         }

         () as sinkPrefixSink = FileSink(SpreadData)   {
            param
                file : "Outliers.AllData.txt";
      }

      () as sinkPrefixSink1 = FileSink(Outliers)   {
            param
                file : "Outliers.Result.txt";
      }
}
```


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Figure 3-12 shows a graph of OrderIdentifierMain.

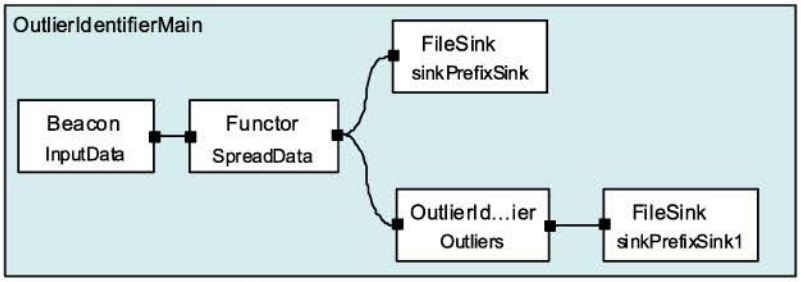


Figure 3-12 OrderIdentifierMain

The first few tuples saved in the `Outliers.AllData.txt` file is shown in the following list. The A - E values in the right column represents the sourceId. The left column contains the generated data value.

- D,0.192206682094148
- D,76.0289535039347
- B,0.107009603935798
- B,5.91479657683522
- B,9.07441698480397
- A,7.40057148071483
- E,9.08254098503395
- D,6.70154246501625
- D,30.2277856968631
- B,5.51431748084724

A sample output of outliers produced by OutlierIdentifers is shown in the following list. From left to right, the columns contain the sourceId, the data value that is an outlier, the average, and the standard deviation.

- A,23.7816749420277,5.35299225659099,8.21130862480932
- A,46.9148279364518,5.35299225659099,8.21130862480932
- B,38.7011607369096,6.29576116903712,9.75789555449789
- B,88.3713359529445,6.29576116903712,9.75789555449789
- B,34.0259439556577,6.29576116903712,9.75789555449789
- D,84.1985481073777,7.30886770639842,11.87863003809
- D,48.6204212472285,7.30886770639842,11.87863003809
- B,67.9634801996605,6.29576116903712,9.75789555449789
- A,34.9190637760897,5.35299225659099,8.21130862480932
- C,49.4983640114433,7.98486332462365,14.0166991654126

Refer to 3.2.1, “Reducing data using a simple filter” on page 82 for a simpler alternative for selecting or filtering streaming data.

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3.2.6 Enriching streams from a database

This design pattern demonstrates how you can enrich a stream with information drawn from a database. An ODBC Enrich operator from the Database Toolkit is used to populate stream data with attributes returned by a database query. This pattern shows how the Enrich operator is used to join with a database table, and thereby add reference information to the stream. This section also references technical guides and example applications that provide the detailed guidance required to configure the connection between the SPL operators and a database.

When to use

Consider using this pattern when you need to enrich the streaming data with relatively static reference information that is stored in a database. In general, to reduce load and latency, extensive reference information should be offloaded to a database, and introduced into your application only when needed. At that point in the data flow, invoke the ODBC Enrich operator to join the stream data with reference information returned from the database. To perform the enrichment, the stream schema must have an attribute, for example, an employee ID, that is shared by both the stream and table schema.

How to use

This example assumes several dependencies related to accessing a database from an SPL application. In particular:

- The Streams Database Toolkit (com.ibm.streams.db), which is packaged with the Streams product. The ODBCEnrich operator is contained in this toolkit.
- A database, with one or more tables containing reference information to be used to enrich the streaming data.
- An ODBC driver, such as UnixODBC. This driver is used by the operators in the Database Toolkit.
- A connections document that specifies access information used by the operators in the SPL Database Toolkit. This information is usually specified in the `etc/connection.xml` file located in your toolkit.

For more information about the Database Toolkit and configuration procedures, refer to:

- IBM InfoSphere Streams Version 2.0.0.2 Database Toolkit,, which can be found by referring to “Online resources” on page 421.
- The odbc_adapters_for_solid_db_at_work sample code is available on the Streams Exchange website, found at the following address:

  https://www.ibm.com/developerworks/mydeveloperworks/files/app?lang=en#/collection/ef9f8aa9-240f-4854-aae3-ef3b065791da

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Input ports
None

Output ports
None

Parameters
$orderStatusStream: A string representing the name of the stream containing order status data. An order status stream is imported by this composite.

Implementation
The example implementation of this pattern enriches a stream containing order status for catalog items with the associated customer, product, and pricing information from a database. The enriched order status records are produced by this example and saved in a file. More specifically, this example works with the following sources of information:

- The OrderShipmentStatus stream, which is input by the Import operator. A tuple is received on this stream whenever the status of the order changes, as examples, order created, order shipped, and order received. This stream consists of OrderId, ShipmentStatus, and ShipmentDate attributes, where the OrderId is assumed to uniquely identify an order.
- A database table of OrderRecords that is accessed by the ODBCEnrich operator. A record is added to this table whenever a new order is created. The schema for this information is defined by the OrderRecord in the composite's `type` clause.

The ODBCEnrich operator enriches the OrderShipmentStatus with the corresponding OrderRecord, and outputs the combined tuples to the EnrichedOrderRecord stream. For each OrderShipmentStatus tuple, the ODBCEnrich operator queries the database specified in the `connection.xml` file for all records containing the same OrderId. The OrderRecord in the result set from the query is then appended to the input tuple to produce the enriched output tuple. The access information and query configuration are defined in the `connection.xml` document referenced by the ODBCEnrich operator. As you would expect, the query is specified as a SELECT statement, where columns correspond to the attributes in the OrderRecord and the WHERE clause filters on the OrderId. The relevant extract from the `connection.xml` is shown in the following example:

```
<query query="select CustomerName, CustomerId, ProductName, ProductId,
       Price from   Order where OrderId = ?" />
<parameters>
  <parameter name="orderId" type="int32" />
</parameters>
```


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The code for the Composite operator my.sample.Main is shown in Example 3-12.

Example 3-12 Code for my.sample.Main

```
composite Main {
  param
    // The OrderStatusStream is used to select streams containing order
    // status data exported by another application.
    // Setting this property at application submission time enables
    // you to configure the stream connection when
    // when the application is launched.
       expression<rstring> $orderStatusStream : getSubmissionTimeValue("OrderStatusStream");
    type
     OrderRecord = int32 OrderId, rstring CustomerName, int32 CustomerId, rstring
        ProductName,
                  int32 ProductId, rstring Price;
     graph
      // Receive tuple that describes change in an order's status - for example order       //
shipped
      stream<int32 OrderId,int32 ShipmentStatus, rstring ShippingDate>
         OrderShipmentStatus = Import() {
        param
          subscription : orderStream==$orderStatusStream;
        }

        // Using the OrderId, enrich the shipment status with customer and product
       // information from DB.
       stream<OrderRecord, tuple<int32 ShipmentStatus, rstring ShippingDate>>
          EnrichedOrderRecord = ODBCEnrich(OrderShipmentStatus) {
           param
             connectionDocument : "./etc/connections.xml" ;
             connection : "SenTestConnection" ;
             access : "readFromOrderTableForEnrich" ;
             orderId : OrderId ;
   }


        // Save enriched tuples in file
        () as SinkOp2 = FileSink(EnrichedOrderRecord) {
           param
             file : "odbc_enrich.result" ;
             format : csv ;
             flush : 1u ;
             writePunctuations : true ;
        }
}
```


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my.sample.Main is shown in Figure 3-13.

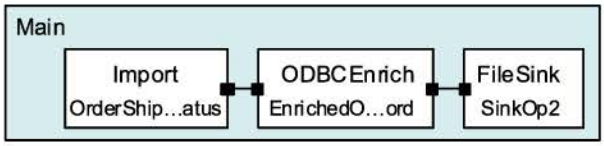


Figure 3-13 my.sample.Main

Walkthrough

The following steps provide a walkthrough for Example 3-12 on page 109:

1. When launching an application that includes this composite, provide a value for the OrderStatusStream submission time parameter. This parameter sets the subscription property used by the Import operator. The Import operator selects streams that are exported with the same name-value property.
2. Whenever a customer's order has been shipped, a tuple is received on the OrderShipmentStatus stream provided by the Import operator.
3. When the ODBCEnrich operator receives the order status tuple, the operator executes the SELECT statement shown above for all records with an OrderId matching the identically named field in the input tuple. The result-set, which contains the CustomerName, CustomerId, ProductName, ProductId, and Price, is combined with the attributes in the input tuple. This extended tuple is output to stream EnrichOrderRecord.
4. The tuples on the EnrichOrderRecord are saved by the FileSink operator to the `odbc_enrich.result` file.

Example

You have the following input tuple on stream OrderShipmentStatus:

```
34567, 1, Sat Feb 19 21:31:12 2011
```

You also have this order record in the OrderResults table in the database:

```
34567, 'John Price', 453234, 'iPod Nano', 53234223, '231.56
```

Given these two items, the ODBCEnrich operator enriches the order status tuple with the OrderResults record to produce:

```
34567, 'John Price', 453234, 'iPod Nano', 53234223, '231.56, 1, Sat Feb
19 21:31:12 2011
```

Refer to 3.2.3, “Data Parallel” on page 90, which describes an approach for running Streams operators in parallel, which may be useful if your application needs to run multiple instances of the enrichment pattern.

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3.2.7 Tuple Pacer

This design pattern is used to pace the flow of tuples within an application. This pattern balances the tuple rates between data producing and consuming operators, which may not be adjacent on a stream.

When to use

Consider using this pattern when you need to explicitly control the tuple processing flow between an upstream data producing operator and downstream data consumers. Note that InfoSphere Streams already provides a built-in queuing mechanism for input ports that calibrate the flow rate between producing and consuming operators on a stream. Streams uses a queue whenever an input port is connected to a stream that crosses PEs, or when the operators are fused in a single PE and a threaded port is configured for the consuming operator. For most applications, this built-in pacing mechanism provides the desired behavior, and the custom solution suggested by this pattern is not required.

However, in cases where it is necessary to regulate the tuple flow across multiple hops, or when custom pacing logic is required, the pattern suggested here might be useful. Suitable examples include scenarios where the application needs to manage the aggregrate flow across multiple operators, or when the pacing logic needs to incorporate parameters other than a queue length (as examples, CPU load, buffer consumption, and so on).

How to use

You may use this pattern in several ways:

- Encapsulate existing graphs between the Gate operator and Custom operator that generates the control tuple.
- Reuse the TuplePacer Composite operator in your own application by interposing this operator in a stream that needs to be paced.
- Update the Custom operators in the TuplePacer (see Example 3-13 on page 112) to invoke your application's business logic. For this example, the business logic is assumed to be contained in functions doWork_0 and doWork_1. These functions are invoked in the logic clause of the Custom operators. The implementation of these functions is not shown.

Input ports

InputStream: An input data stream.

Output ports

PacedOutputStream: A stream where the data is paced.

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Parameters

$maxQueueLength: expression<int32>, which is the size of the port queue used for inbound tuples.

Implementation

This pattern is built around a Gate operator, which forwards tuples, and a complementary downstream Custom operator, which emits a "control" tuple that is treated as an acknowledgment. In the diagram, the rightmost Custom operator produces the control tuple. The Custom operator in the middle is performing the analytic work on the inbound tuples. The Gate operator uses two input streams: data and control. This operator paces the flow of tuples on the input data stream by requiring a control tuple to acknowledge that previously sent tuples have been processed; an indicator that the downstream operators are ready to receive the next tuples. The Custom operator generates a control tuple containing the count of the number of inbound tuples that have been processed and are being acknowledged. Any number of operators that process the data may be interposed between the Gate and Custom operators.

The code for the Composite operator com.ibm.designpatterns.pacer.TuplePacer is shown in Example 3-13.

Example 3-13 Composite operator for TuplePacer

```
composite TuplePacer(output PacedOutputStream; input InputStream) {
       param expression<int32> $maxQueueLength;
       graph
         stream<StreamType> GatedData_0 = Gate(InputStream; Control) {
              // No more than 10 tuples may be sent prior to
              // receiving an acknowledgement
              param maxUnackedTupleCount : 10u;
                    // Indicates the number of tuples being acknowleged.
                    numTuplesToAck : Control.count;

         }

         stream<StreamType> GatedData_1 = Custom(GatedData_0) {
              logic onTuple GatedData_0:
              {
                // Process input tuple data. Implementation of the doWork_0 function
                // is not shown.
                doWork_0(GatedData_0);
                // Forward processed data
                submit(GatedData_0, GatedData_1);
              }
         }
```


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```
        (stream<StreamType> PacedOutputStream; stream<uint32 count> Control)
           = Custom(GatedData_1) {
             logic onTuple GatedData_1:
             {
               // Process input tuple data. Implementation of the doWork_1 function
               // is not shown.
               doWork_1(GatedData_1);
               // Forward processed data
               submit(GatedData_1, PacedOutputStream);
               // Acknowledge one tuple
               submit({count = 1u}, Control);
             }
             // Input port queue won't have more than 10 (the value of
             // maxUnackedTupleCount)tuples even though the max queue size specified
             // is larger than the $maxQueueLength
             config threadedPort : queue(GatedData_1, Sys.Wait, $maxQueueLength);
        }
}
```

The Composite operator TupIdPacer is shown in Figure 3-14.

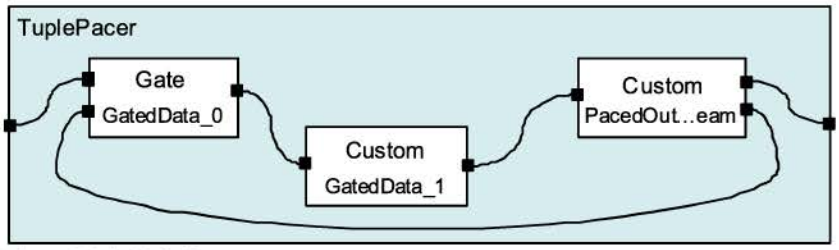


Figure 3-14 TuplePacer

Walkthrough

The following steps describe a flow through the TuplePacer (Example 3-13 on page 112) when the data consuming operators are keeping up with the rate of inbound data tuples:

1. The Gate operator receives the first data tuple on the InputStream stream.
2. Because the Gate operator is configured to continue forwarding tuples until more than 10 tuples are not acknowledged, the first tuple is forwarded on output stream GatedData_0. The count of unacknowledged tuples maintained by the Gate operator is incremented, and now equals 1.

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3. The first tuple is received by the Custom operator that outputs stream GatedData_1. This operator invokes function doWork_0 to process the tuple, and forwards the results on GatedData_1.
4. The data tuple is next received by the Custom operator that implements the control logic for producing acknowledgements. This operator forwards the data tuples on the PacedOutputStream. A control tuple that acknowledges that a data tuple has completed processing is sent on the output stream named Control. For each data tuple received, this Custom operator invokes function doWork_1 to process the data tuple. After the tuple has been processed, a control tuple is sent with a count set to 1 to indicate that a single data tuple is being acknowledged.
5. The Gate operator receives the acknowledgement on the input Control stream. Given this acknowledgement, the Gate operator decrements the count of unacknowledged tuples by 1 (the value of the count attribute). Because the value of the counter is 1, as set in step 1 on page 113, the counter of unacknowledged tuples is reset to 0. The next inbound tuple will be immediately forwarded.

In the case where the processing time of the data consuming operators exceeds the inter-arrival rate of the inbound data, tuples will start to build up on the queue associated with the threaded port of the GatedData_1custom operator. When this happens, the flow rate is calibrated as follows:

1. The Gated operator continues to forward data tuples on the GatedData_0 stream until the 10 tuples are sent and no acknowledgement has been received. At this point, the Gate suspends forwarding the inbound tuples. The inbound tuples will back up on the queue of the Gate operator's threaded port.
2. Whenever the GatedData_1 customer operator completes processing an inbound tuple, it will generate an acknowledgment for that tuple on the Control stream.
3. When the Gate operator receives the acknowledgment, it will decrement the unacknowledged tuple count from 10 to 9. Because the unacknowledged tuple count is less than 10, the Gate operator will dequeue and forward a tuple from the InputStream and increment the unacknowledged tuple count to 10. Any tuples now received on the InputStream will be queued until the next acknowledgement is received.

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Example

Example 3-14 illustrates how the TuplePacer operator may be invoked. When installing this pattern in your own application, the imported stream may be replaced by the output of a sub-graph that you want to pace. Similarly, the Export operator may be replaced by the SPL code that consumed the paced stream.

Example 3-14 Invoking the TuplePacer operator

```
composite TuplePacerMain {
   graph
     stream<StreamType> InputStream = Import() {
          param subscription : InboundTuples;
     }
     // No more than 1000 tuples may be queued awaiting for processing.
     stream<StreamType> PacedStream = TuplePacer(InputStream){
          param maxQueueLength : 1000;
     }
     stream<StreamType> OutputStream = Export(PacedStream) {
          param streamId : PacedTuples;
     }
}
```

Figure 3-15 shows TuplePacerMain.

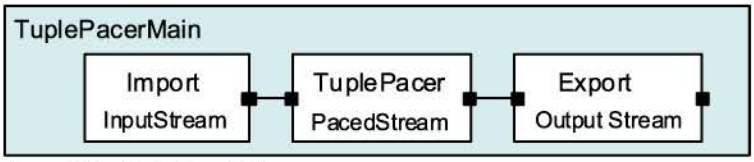


Figure 3-15 TuplePacerMain

Refer to the following items:

- Section 3.2.11, “Adapting to observations of runtime metrics” on page 134. This design pattern addresses a related scenario where the application adjust its workload dynamically.
- The spl.utility.Gate operator in the InfoSphere Streams SPL Standard Toolkit Reference. For the Toolkit location, refer to “Online resources” on page 421.
- The spl.utility.Throttle operator in the InfoSphere Streams SPL Standard Toolkit Reference. For the Toolkit location, refer to “Online resources” on page 421.

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3.2.8 Processing multiplexed streams

This design pattern is about processing multiplexed streams. It is often the case that a stream contains multiple logical sub-streams in it, where each logical stream requires processing and a state independent of the others. A typical example is computing the volume weighted average price (VWAP) for each stock ticker in a financial trading application. In this example, the tuples corresponding to a particular stock ticker constitutes a logical stream and the VWAP is computed over this logical stream independent of the others.

When to use

This pattern is useful when the application contains streams that carry multiplexed sub-streams in them and there is a requirement to process the sub-streams independently of each other. A stream is often multiplexed by identifying one or more attributes as the partitioning key, which is often referred to as "partition-by-attributes" in SPL.

How to use

To use this pattern, first a set of attributes on a stream are identified as the partition-by-attributes. Then the stream is processed by taking it through one or more partitioned-stateful operators that are capable of processing multiplexed streams, or through stateless operators. In the SPL Standard Toolkit, partitioned-stateful operators consistently provide a partitionBy attribute that can be used to configure them to perform processing on multiplexed streams such that the processing is performed and state is maintained, independently for each sub-stream. For partitioned-stateful Custom operators in SPL and primitive operators developed by third parties, use a partitionBy parameter. A common way of implementing this setup is to organize the state kept by the operator inside a map, and use the partition-by-attribute of the incoming tuple to locate the subset of the state that corresponds to the sub-stream to which the input tuple belongs, and operate on the state.

Implementation

Here we provide an application example, RevenueBySector, where we apply this pattern using an SPL Standard Toolkit operator, as well as a Custom SPL operator that we develop. The goal of the application is to read a list of data items from a file, where the data items contain information about revenues of companies. Each company belongs to an industry. We identify the industry as the partition-by-attribute. The goal is to compute the total revenue per industry and write the result to a file, where we want one result file per-industry, containing that industry's total revenue.

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The MultiFileWriter is a Composite operator that is implemented in SPL using a Custom operator. It creates a file for each unique session attribute value and writes all tuples with the same session ID to the corresponding file. Internally, it uses an SPL map to maintain the partition by attribute to file handle mapping. For each tuple it receives, it uses the session attribute to locate the appropriate file handle. If the file handle is not there, it creates it (the session is seen for the first time). On receiving the final punctuation, it flushes the files. The code for the MultiFileWriter follows the listing of the RevenueBySector composite.

The code for the Composite operator com.ibm.designpatterns.demultiplexstream.RevenueBySector is shown in Example 3-15.

Example 3-15 Composite operator for RevenueBySector

```
composite RevenueBySector {
  type
    Revenue = tuple<rstring sector, rstring company, float64 revenue>;
    SectorRevenue = tuple<rstring sector, float64 revenue>;
  graph
    stream<Revenue> Revenues = FileSource() {
      param
        file : "input";
        format : csv;
    }
    stream<SectorRevenue> TotalRevenuesBySector = Aggregate(Revenues) {
      window
        Revenues: partitioned, tumbling, punct();
      param
        partitionBy: sector;
      output
        TotalRevenuesBySector: revenue = Sum(revenue);
    }
    () as Sink = MultiFileWriter(TotalRevenuesBySector) {
      param
        partitionBy: sector;
        fileNamePrefix: "output_";
    }
}
```


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The Composite operator RevenueBySector is shown in Figure 3-16.

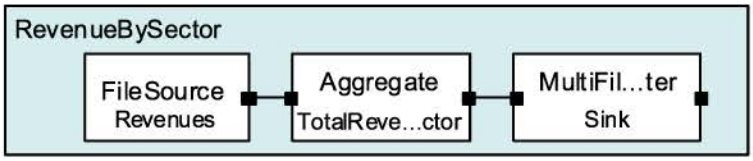


Figure 3-16 RevenueBySector

The code and graph diagram for the MultiFileWriter Composite operator is shown in Example 3-16.

Example 3-16 Composite MultiFileWriter

```
composite MultiFileWriter(input S)
{
  param
    expression $partitionBy;
    expression<rstring> $fileNamePrefix;
  graph
    () as Sink = Custom(S) {
      logic
        state :
          mutable map<rstring, uint64> files = {};
        onTuple S: {
          rstring key = (rstring) $partitionBy;
          rstring file = $fileNamePrefix + key;
          if (!(key in files)) {
            mutable int32 err = 0ul;
            uint64 fd = fopen(file, "w", err);
            if (err!=0)
              log(Sys.error, "Cannot open file '"+file+"' for writing");
            else
              files[key] = fd;
          }
          if(key in files) {
            mutable int32 err = 0ul;
            fwriteTxt(S, files[key], err);
            if (err!=0)
              log(Sys.error, "Cannot write to file '"+file+"'");
            fwriteString("\n", files[key], err);
          }
        }
        onPunct S: {
```


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```
            mutable int32 err = 0;
            if (currentPunct()==Sys.FinalMarker)
              for (rstring key in files)
                fclose(files[key], err);
        }
    }
}
```

The Composite operator MultiFileWriter is shown in Figure 3-17.

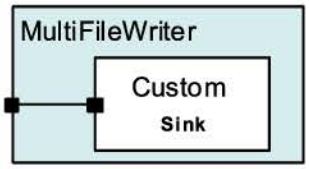


Figure 3-17 MultiFileWriter

Walkthrough

The following steps provide a walkthrough for Example 3-15 on page 117 and Example 3-16 on page 118:

1. Revenue is a tuple type that describes the revenue of a company, including the company's sector.
2. SectorRevenue is a tuple type that describes the revenue of a sector.
3. The FileSource operator, shown in Example 3-15 on page 117, is used to create a stream out of the input file `input`.
4. The results of the FileSource operator is fed into an Aggregate operator, which is configured with a partitionBy parameter where the partition by attribute is identified as the sector. The aggregation has a punctuation based window, which means that the entire input stream will be aggregated (the entire file). In a more practical variation of this application, the window can be count or time based.
5. The results from the Aggregate operator, which will include one tuple per session, are fed into the MultiFileWriter operator. Again, the partitionBy parameter is specified and the session attribute is used as its value.
6. For each sector, the MultiFileWriter, shown in Example 3-16 on page 118, creates a separate output file to store the total revenue for the sector. The contents of the tuple containing the aggregated results for the sector are written to the output file.
7. The output files are closed when a final punctuation is received.

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Example

Given the following input:

```
technology, IBM, 100
finance, "American Express", 50
aerospace, Boeing, 150
technology, HP, 100
aerospace, "Lockheed Martin", 150
technology, MS, 100
finance, "Goldman Sachs", 50
```

The program generates the following output:

```
output_aerospace
================
{sector="aerospace",revenue=300}

output_finance
==============
{sector="finance",revenue=100}

output_technology
=================
{sector="technology",revenue=300}
```

Refer to 3.2.3, "Data Parallel" on page 90 for more information. This design pattern may be used to process the logical sub streams in parallel.

3.2.9 Updating import stream subscriptions

This design pattern shows how to dynamically update the stream subscription specified as part of an Import operator. The Import operator has a subscription parameter that specifies an expression to be evaluated against the stream properties of exported streams. Based on this evaluation performed at run time, new stream connections are established. The goal of this pattern is to show how this subscription expression can be updated at run time.

When to use

A common use case is to update the subscription expression based on the changing needs of the downstream processing. As an example, consider a video monitoring application that watches who enters and leaves a building. The subset of video source streams that are of interest to the application can change based on the analysis performed.

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For example, if the monitoring application detects high activity on the camera feed that provides a view of the front door, it might decide to start processing feeds from additional cameras that provide close-up views of the door.

How to use

For a realistic implementation of this pattern, the ImportController Composite operator, described in the following text, would ingest a data stream from one of the cameras monitoring the front door. The logic in this operator would be updated to generate subscription properties based on the level of activity reported by the camera. Additionally, the Importer and Exporter operators would likely be implemented in separate SPL applications. The stream connections from the export to the import operators would be established when the applications are deployed to the run time.

Implementation

Import operators are pseudo-operators in SPL. The import subscriptions are associated with the input ports of the downstream operators that consume the stream produced by the Import operator. Those operators can update the import subscription associated with their input port at run time. At the time of the writing of this book, these APIs are only available to Primitive operators, but future versions of Streams will make them available to Custom operators as well.

We showcase the implementation of this pattern using a sample application that uses dynamic subscription updates to switch between receiving one of two exported streams. As part of this application, we will make use of a Primitive operator called DynamicImporter. This operator is connected to the output of the Import operator and forwards the imported stream. At the same time, it accepts subscription expressions as tuples on a second (control) port and uses the runtime APIs to update the subscription expression associated with the first input port.

In addition to the Importer that updates the stream subscription, this section includes the code and graph diagrams for the Exporter, SourceGen, and ImportController operators. The Exporter and SourceGen operators collaborate to generate an exported stream that is consumed by the Import operator in the Importer. The ImportController serves this example by periodically producing a control tuple containing the new subscription expression. The top of the code example, shown in Example 3-17, is a Main that invokes both the Exporter and Importer.

Example 3-17 Composite using the Exporter and Importer

```
// A main composite that invokes both the stream exporter and importer.
composite Main {
  graph
```


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```
    () as E = Exporter() {}
    () as I = Importer() {}
}

// This operator exports two streams
composite Exporter {
  graph
    // We export a stream with an export property of name="A"
    stream<int32 id, rstring name> DataA = SourceGen() {
      param
        name : "A";
    }
    () as ExporterA = Export(DataA) {
      param
        properties : { name = "A" };
    }
    // We export a stream with an export property of name="B"
    stream<int32 id, rstring name> DataB = SourceGen() {
      param
        name : "B";
    }
    () as ExporterB = Export(DataB) {
      param
        properties : { name = "B" };
    }
}

// This operator is used as a workload generator
composite SourceGen(output Out) {
  param
    expression<rstring> $name;
  graph
    stream<int32 id> Src = Beacon() {
      logic
        state: mutable int32 cnt=0;
      param
        period: 0.25;
      output
        Src: id = cnt++;
    }
    stream<int32 id, rstring name> Out = Functor(Src) {
      output
        Out: name = $name+"_"+(rstring)id;
    }
}
```


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```
// This operator imports an alternating stream
composite Importer {
  graph
    stream<int32 id, rstring name> Imported = Import() {
      param
        subscription : name=="B";
    }
    stream<Imported> DynImported = DynamicImporter(Imported; Control)
       {}
    stream<rstring subscription> Control = ImportController() {}
    () as Sink = FileSink(DynImported) {
      param
        file: "results";
        flush: 1u;
    }
}

// This operator periodically produces a new subscription expression
composite ImportController(output Out) {
  graph
    stream<int8 dummy> Beat = Beacon() {
      param
        iterations: 1u;
    }
    stream<rstring subscription> Out = Custom(Beat) {
      logic
        onTuple Beat: {
          while(!isShutdown()) {
            block(1.0);
            submit({subscription="name==\"A\""}, Out);
            block(1.0);
            submit({subscription="name==\"B\""}, Out);
          }
        }
    }
}
```


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Figure 3-18 shows Main composite for importing and exporting.

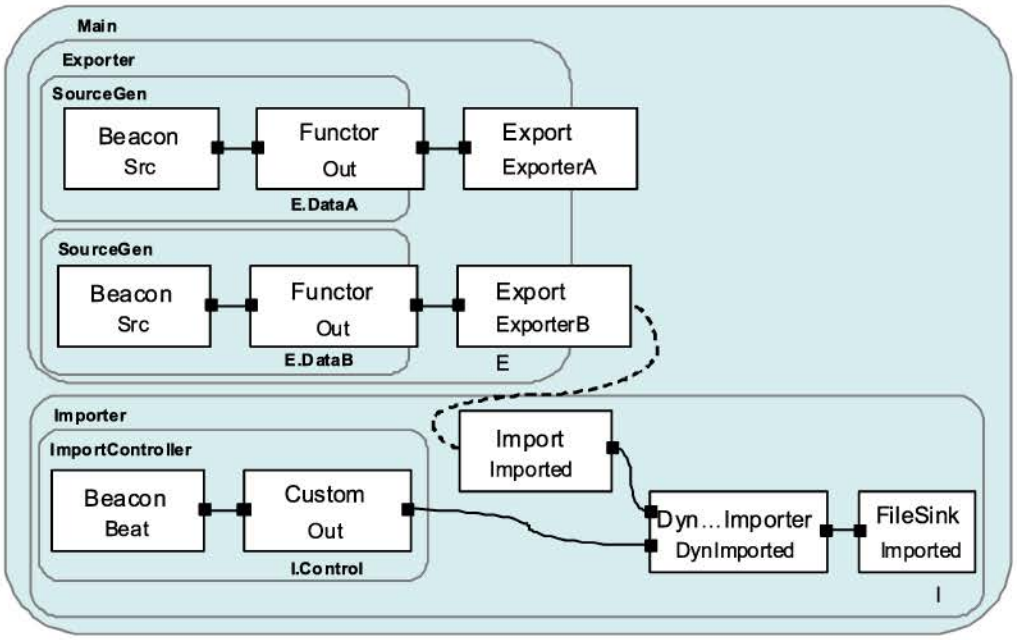


Figure 3-18 The expanded Main composite for importing and exporting

Where:

- The pseudo Import and Export operators are shown in the graph. The connection between the Export and Import operators enables the stream data to flow from the Exporter to Importer Composite operators.
- Note that stream data flows from the composite Export operator to the Import operator (dashed line). Also note that they are pseudo operators and as such do not terminate with an operator port as do the other streams operators.
- Composite E is exporting streams DataA and DataB, with property values name = “A” and name = “B”, respectively.
- Composite I dynamically toggles between importing streams DataA and DataB. In the example code above, the Import operator in composite I is initialized to import DataB.
- The name of the DynamicImporter has been abbreviated to Dyn...Importer.

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Walkthrough

The Main Composite invokes the Importer and the Exporter Composites. These are two independent flows. In a real world application of this pattern, it is more likely that the Importer and the Exporter are part of different applications.

The following steps provide a walkthrough for Figure 3-18 on page 124:

1. The Exporter Composite operator creates and exports two streams. The first stream is exported with a name property of value “A” and the second stream is exported with a name property of value "B". Both of the streams are generated using the SourceGen Composite operator.
2. The SourceGen Composite operator is a simple workload generator that uses Beacon and Functor operators to generate periodic tuples with increasing numeric identifiers and a string attribute that has a prefix followed by the same numeric ID. The prefix is a parameter of the SourceGen operator.
3. The Importer Composite operator imports the stream with the name property value of “A" using an Import operator. The Import operator is connected to a DynamicImporter Primitive operator. This Primitive operator controls the import subscription of the Import operator. It has a control input port that receives tuples that contain subscription expressions as string attributes. Whenever a new subscription expression is received, this operator will update the Import operator's subscription expression. The control input port of the DynamicImporter operator is fed by the output of a ImporterController operator, which we describe next. Finally, the results from the DynamicImporter are sent to a FileSink operator, which writes the results to a file.
4. The ImportControllerComposite operator uses a Custom operator to periodically generate a tuple that contains an alternating subscription expression string, one of anaemia” or nameable”.

The C++ code that implements the DynamicImporter operator is shown in Example 3-18.

Example 3-18 DynamicImporter operator

```
void MY_OPERATOR::process(Tuple const & tuple, uint32_t port)
{
    if(port==1) { // control tuple, update the subscription expression
        for (ConstTupleIterator it=tuple.getBeginIterator();
             it!=tuple.getEndIterator(); ++it) {
            ConstValueHandle handle = (*it).getValue();
            if(handle.getMetaType()==SPL::Meta::Type::RSTRING) {
                rstring const & exp = handle;
                try {
                    getInputPortAt(0).setSubscriptionExpression(
```


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```
                    *SubscriptionExpression::fromString(exp));
                break;
            } catch(...) {}
        }
    }
} else { // data tuple, just forward
    submit(tuple, 0);
}
}
```

Example

As it can be seen from the DynamicImporter code shown in Example 3-18 on page 125, the data tuples are forwarded from the first input port to the output port, and the control tuples from the second input port are used to update the subscription expression associated with the first input port.

A fragment of results from running this application is shown in the following list. Note that the stream subscription toggles every three or four tuples, which is expected, as Composite E generates four tuples per second on each output steam, and the ImportController emits a control message that switches the stream subscription once per second.

```
613,"A_613"
614,"A_614"
615,"A_615"
616,"A_616"
617,"B_617"
618,"B_618"
619,"B_619"
621,"A_621"
622,"A_622"
623,"A_623"
624,"B_624"
625,"B_625"
626,"B_626"
627,"B_627"
```

Refer to 3.2.10, “Updating export stream properties” on page 127 for more information. This pattern shows how to write a Primitive operator that updates a stream's export properties at run time.

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3.2.10 Updating export stream properties

This design pattern shows how to dynamically update the stream properties specified as part of an Export operator. The Export operator has a properties parameter that specifies a list of properties to be evaluated against the stream subscriptions of imported streams. Based on this evaluation performed at run time, new stream connections are established. The goal of this pattern is to show how these properties can be updated at run time.

When to use

A common use case is to update the export properties based on the changing characteristics of the exported stream. As an example, consider one or more applications performing analysis on different news feeds. Based on the analysis performed by an application, the resulting news stream can be associated with a priority property. This property can change depending on the current contents of the associated feed. An importing application can specify a stream subscription that only receives news feeds with high priority. The exporting applications, by updating their priority property at run time, enable the downstream applications to import only the relevant news feeds.

How to use

The example pattern shown here employs several simplifications that would likely be changed for commercial implementations. In particular:

- Both the Exporter and Importer operators are invoked by the same main Composite. A more useful implementation would be to invoke each of these Composite operators from separate main Composites. As a result, these applications would be able to be submitted to the Streams run time separately. A Stream connection between the Export and Import operators contained in these Composites would be established dynamically, provided that the subscription expression matches the export properties.
- The ExportController Composite operator would be replaced or updated with an operator that changed the export priority based on an inspection of the news feed data. The implementation used in this example periodically updates the priority, which is appropriate for demonstration only.

Implementation

Export operators are pseudo-operators in SPL. The export properties are associated with the output ports of the upstream operators that produce the stream consumed by the Export operator. Those operators can update the export properties associated with their output port at run time. At the time of the writing of this book, these APIs are only available to Primitive operators, but future versions of Streams will make them available to Custom operators as well.

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We showcase the implementation of this pattern using a sample application that uses dynamic stream property updates to switch between sending data to one of two downstream importers. As part of this application, we make use of a Primitive operator called DynamicExporter. This operator receives the stream to be exported and forwards it to the Export operator. At the same time, it accepts new stream properties as tuples on a second (control) port and uses the runtime APIs to update the stream properties associated with its output port.

We provide the code for the application in Example 3-19.

Example 3-19 DynamicExporter

```
composite Main {
  graph
    () as E = Exporter() {}
    () as I = Importer() {}
}

composite Exporter {
  graph
    stream<int32 id, rstring time> Exported = SourceGen() {}
    stream<Exported> DynExported = DynamicExporter(Exported; Control) {}
    stream<rstring priority, int64 level> Control = ExportController() {}
    () as Exporter = Export(DynExported) {
        param
            properties : {priority="low", level=41};
    }
}

composite SourceGen(output Out) {
  graph
    stream<int32 id, rstring time> Out = Beacon() {
      logic
        state : mutable int32 cnt=0;
        param
          period : 0.25;
        output
          Out: id = cnt++, time=ctime(getTimestamp());
    }
}

composite ExportController(output Out) {
  graph
    stream<int8 dummy> Beat = Beacon() {
      param
        iterations: 1u;
```


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```
    }
    stream<rstring priority, int64 level> Out = Custom(Beat) {
      logic
        onTuple Beat: {
          while(!isShutdown()) {
            block(1.0);
            submit({priority="high", level=3l}, Out);
            block(1.0);
            submit({priority="low", level=4l}, Out);
          }
        }
    }
}

composite Importer {
  graph
    stream<int32 id, rstring time> ImportedA = Import() {
      param
        subscription : priority=="high" && level==3l;
    }
    () as SinkA = FileSink(ImportedA) {
      param
        file: "results.A";
        flush: 1u;
    }
    stream<int32 id, rstring time> ImportedB = Import() {
      param
        subscription : priority=="low" && level==4l;
    }
    () as SinkB = FileSink(ImportedB) {
      param
        file: "results.B";
        flush: 1u;
    }
```


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We provide a diagram of the application in Figure 3-19.

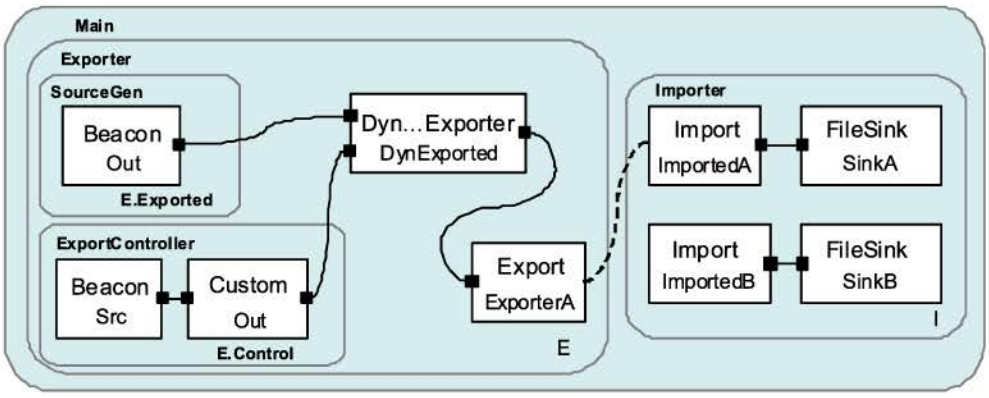


Figure 3-19 DynamicExporter

Where:

- DynamicExported is labelled as Dyn...Exporter, which is an abbreviation.
- Composite E is exporting stream DynExported, with property values priority="low", level=4I.
- The connection between the Export operator in the Exporter and one of the Import operators in the Importer represents the exported stream property being updated.
- Note that stream data flows from the composite Export operator to the Import operator (dashed line). Also note that they are pseudo operators and as such do not terminate with an operator port as do the other streams operators.
- Composite I dynamically toggles between importing the stream DynExported into one of the two FileSink operators. In the example code above, the Export operator in Composite E is initialized to send data to the first FileSink.

The C++ code for the process function of the DynamicExporter operator is shown in Example 3-20.

Example 3-20 Dynamic Exporter application C++ code

```
void MY_OPERATOR::process(Tuple const & tuple, uint32_t port)
{
    if(port==1){
        OperatorOutputPort & oport = getOutputPortAt(0);
        StreamPropertyCollection newCol;
        for (ConstTupleIterator it=tuple.getBeginIterator();
```


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```
             it!=tuple.getEndIterator(); ++it) {
            ConstValueHandle handle = (*it).getValue();
            std::string name = (*it).getName();
            StreamProperty prop;
            bool success = setStreamProperty(name, handle, prop);
            if (success)
                newCol.push_back(prop);
        }
        try {
            StreamPropertyCollection oldCol;
            oport.getStreamProperties(oldCol);
            std::vector<std::string> names;
            for (StreamPropertyCollection::const_iterator
                   it=oldCol.begin(); it != oldCol.end(); ++it)
                names.push_back(it->getName());
            oport.removeStreamProperties(names);
            oport.addStreamProperties(newCol);
        } catch(...) {}
    } else {
        submit(tuple, 0);
    }
}

bool MY_OPERATOR::setStreamProperty(std::string const & name,
    ConstValueHandle handle, StreamProperty & prop)
{
    Meta::Type type = handle.getMetaType();
    switch (type) {
        case Meta::Type::RSTRING: {
            rstring const & value = handle;
            prop = StreamProperty(name, value);
            return true;
        }
        case Meta::Type::INT64: {
            int64 const & value = handle;
            prop = StreamProperty(name, value);
            return true;
        }
        case Meta::Type::FLOAT64: {
            float64 const & value = handle;
            prop = StreamProperty(name, value);
            return true;
        }
        case Meta::Type::LIST: {
            List const & value = handle;
```


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```
            Meta::Type elemType = value.getElementMetaType();
            switch (elemType) {
                case Meta::Type::RSTRING: {
                    list<rstring> const & lstValue = static_cast<list<rstring>
                       >(value);
                    prop = StreamProperty(name, lstValue);
                    return true;
                }
                case Meta::Type::INT64: {
                  list<int64> const & lstValue = static_cast<list<int64> >(value);
                    prop = StreamProperty(name, lstValue);
                    return true;
                }
                case Meta::Type::FLOAT64: {
                    list<float64> const & lstValue = static_cast<list<float64>
                       >(value);
                    prop = StreamProperty(name, lstValue);
                    return true;
                }
                default: return false;
            }
        }
        default: return false;
    }
    return false;
}
```

Walkthrough

The following steps provide a walkthrough for Example 3-20 on page 130:

1. The Main Composite invokes the Importer and the Exporter Composites. These are two independent flows. In a real world application of this pattern, it is more likely that the Importer and the Exporter flows are part of different applications.
2. The Exporter Composite operator creates and exports a stream. This stream is generated using the SourceGen Composite operator. The generated stream is fed into the DynamicExporter Primitive operator. This Primitive operator controls the export properties of the Export operator that consumes its output. It forwards the stream that it receives on its input port to the Export operator and uses the tuples it receives on its second input port to control the export properties. Whenever a new tuple is received on the control port, this operator will use the attribute names and values form the tuple to update the Export operator's export properties.

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The Export operator has an initial set of export properties specified, which will be replaced by the DynamicExporter Primitive operator at run time.

3. The SourceGen Composite operator is a simple workload generator that uses a Beacon operator and a Functor operator to generate periodic tuples with increasing numeric identifiers and a string attribute that carries the current time.
4. The ExportController Composite operator uses a Custom operator to periodically generate a tuple that contains an alternating set of export properties, one of {priority="high", level=3l} or {priority="low", level=4l}.
5. The Importer Composite operator imports two streams, one using a subscription expression that matches priority=="high" && level==3l and another that matches priority=="low" && level==4l. As the export properties switch from one to the next, one of these imports stops receiving tuples where the other one will start receiving them.

Example

As can be seen from the code, the data tuples are forwarded from the first input port to the output port, and the control tuples from the second input port are used to update the export properties associated with the output port.

A fragment of results from running this application is given in Table 3-1. Note that the export properties toggle around every four tuples. This is expected, as Composite E generates four tuples per second on each output steam, and the ExportController emits a control message that switches the stream subscription once per second.

Table 3-1 Application results

results.A	results.B
25,"Fri Aug 5 11:15:44 2011"	29,"Fri Aug 5 11:15:45 2011"
26,"Fri Aug 5 11:15:44 2011"	30,"Fri Aug 5 11:15:45 2011"
27,"Fri Aug 5 11:15:45 2011"	31,"Fri Aug 5 11:15:46 2011"
28,"Fri Aug 5 11:15:45 2011"	32,"Fri Aug 5 11:15:46 2011"
33,"Fri Aug 5 11:15:46 2011"	37,"Fri Aug 5 11:15:47 2011"
34,"Fri Aug 5 11:15:46 2011"	38,"Fri Aug 5 11:15:47 2011"
35,"Fri Aug 5 11:15:47 2011"	39,"Fri Aug 5 11:15:48 2011"
36,"Fri Aug 5 11:15:47 2011"	40,"Fri Aug 5 11:15:48 2011"

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Refer to 3.2.9, “Updating import stream subscriptions” on page 120 more information. This pattern shows how to write a Primitive operator that updates a stream's import properties at run time.

3.2.11 Adapting to observations of runtime metrics

This design pattern concerns adapting to changes based on observations of system or user-defined metrics. We first briefly look at what metrics are, and then discuss how they can be used for adapting to changes.

The metrics support of Streams provides two types of metrics:

- System-supplied metrics
- User-defined metrics

System-supplied metrics are provided by the run time without any additional help from the developers. As an example, the number of tuples submitted by an operator port is a metric that the system keeps track of and makes available.

User-defined metrics are defined by the operator developers and their values are updated by the operator implementations. As an example, the number of invalid input lines could be a metric a Source operator can maintain, which the system then makes available.

The metrics are made available to both SPL application and external tools, such as scripts and programs. For applications, operator-level APIs are provided to access metrics associated with operators and PEs. Such APIs provide access to local metrics only (each operator can only access metrics that pertain to itself). These metrics can be used by the operator to adapt its behavior. As an example, by looking at a metric that specifies the number of tuples queued up on an operator's input port, the operator can adapt the processing it does to reduce the load.

For the scripts and programs, the set of all metrics associated with the applications and the Streams middleware components are made available, subject to security constraints. External tools, such as application management scripts, can poll the system for these metrics and take action depending on the metric values. The streamtool **`capturestate command`**, which is documented the IBM InfoSphere Streams Installation and Administration Guide (located at the address `http://publib.boulder.ibm.com/infocenter/streams/v2r0/topic/com.ibm.swg.im.infosphere.streams.product.doc/doc/IBMInfoSphereStreams-InstAdmin.pdf`), returns an XML document containing a snapshot of the performance metrics.

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As an example, in an anomaly detection application, a user-defined metric provided by the application can be used by an application management script to determine that a suspicious condition has been detected, and as an action, the script could decide to launch a new application piece that does deeper analysis.

When to use

This pattern is useful when the knowledge obtained from metrics can be used by the application to adapt its behavior. Examples include, but are not limited to:

- Reactive-analytics: Information derived from metrics can be used to launch new applications, stop or replace jobs, or adapt to changing goals derived from the current processing.
- Load shedding: Performance metrics can be inspected to change the nature of the processing performed to adapt to the current load.

How to use

Add calls to the SPL functions that return operator metrics in the onTuple clause as shown in Example 3-21. In addition to the getInputPortMetricValue function, the getOutputPortMetricValue and getCustomMetricValue functions are available to retrieve built-in metrics associated with output ports, and custom user-defined customer metrics, respectively.

Implementation

In the implementation shown below, the Beacon and Throttle operators are used to feed a stream of tuples at a consistent rate to the Custom operator. The purpose of this Custom operator is to process the inbound tuple using either an expensive (doWorkFull) or cheap (doWorkCheap) algorithm, depending on the number of tuples waiting to processed. For each tuple, the Custom operator invokes the built-in getInputPortMetricValue function to obtain the number of tuples that are currently queued on its input port. If the more than 500 (represented as a constant "500l" of type long) tuples are queued, the cheap algorithm, which produces approximate results, is invoked. Otherwise, the input port is assumed to not be too congested, and the expensive, and presumably more precise, algorithm is used.

After 100,000 tuples are processed, the Beacon operator quiesces and produces a final punctuation. When this punctuation is received, the Custom operator prints out a the total number of times it invoked the cheap and expensive algorithms. The code for this application is shown in Example 3-21.

Example 3-21 Operator metrics

```
types
  Any = tuple<int32 data>;
```


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```
composite Main {
  graph
    stream<Any> Source = Beacon() {
      param
        iterations: 100u * 1000u;
    }

    stream<Any> Throttled = Throttle(Source) {
      param
        rate : 100000.0;
        precise : true;
    }

    () as Worked = Custom(Throttled as I) {
      logic
        state: {
          mutable uint64 cheap = 0, full = 0;
        }
    onTuple I: {
      mutable int64 nQueued = 0;
      getInputPortMetricValue(0u, Sys.nTuplesQueued, nQueued);
      if(nQueued>5001) {
        cheap++;
        doWorkCheap(I);
      } else {
        full++;
        doWorkFull(I);
      }
      }
    onPunct I : {
      if(currentPunct()==Sys.FinalMarker)
       printString("cheap="+(rstring)cheap+" "+
                   "full="+(rstring)full);
     }
   config
     threadedPort: queue(I, Sys.Wait, 1000);
    }
}

stateful void doWorkCheap(tuple<Any> work)
{
  // cheap but low accuracy
}

stateful void doWorkFull(tuple<Any> work)
```


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```
{
  // costly but high accuracy
  block(0.0001);
}
```

We provide a diagram of the application in Figure 3-20.



Figure 3-20 Operator metrics

Walkthrough

The following steps provide a walkthrough for Example 3-21 on page 135:

1. The first operator is a Beacon that produces a stream of tuples.
2. It is followed by a Throttle operator that throttles the Stream to 100,000 tuples per second.
3. The throttled stream is fed to a Custom operator that performs some custom logic.
4. The Custom operator has a threaded input port, and thus a queue associated with it.
5. The Custom operator inspects the queue size and if it detects that the queue is more than half full, it switches to processing tuples using the “cheap” algorithm that is low accuracy. Whenever the queue size goes below 500, it goes back to using the “full” algorithm that has high accuracy.
6. When all the data is processed, the Custom operator prints the number of times the “cheap” and the “full” versions of the algorithm were used.

Example

The result from running this example application (in stand-alone mode) looks like the following:

```
cheap=94959 full=5041
```

Additional reading

Refer to the *Streams Installation and Administration Guide* for the use of streamtool to access system and application metrics from the command line. This document comes with the Streams product.

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Refer to *SPL Standard Toolkit Types and Functions* for the use of SPL APIs to access metrics. For the Toolkit location, refer to "Online resources" on page 421.

Refer to 3.2.7, "Tuple Pacer" on page 111 for more information. This pattern shows how to adapt to changes by pacing the flow of tuples to match the processing speed of a downstream operator.

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4

InfoSphere Streams deployment

In this chapter, we describe InfoSphere Streams runtime deployment, which includes planning, installation, and configuration of the InfoSphere Streams run time on Linux clusters and configuration of Streams instances. In addition, we discuss Streams application deployment capabilities.

The following topics are discussed:

- InfoSphere Streams runtime deployment
  - Streams runtime architecture and services
  - Streams instances, and deployment topologies
  - Planning a Streams runtime deployment
  - Pre- and post-installation and configuration of the Streams environment
- InfoSphere Streams instance creation and configuration
  - Streams shared instance planning and configuration
  - Streams private development instance configuration
- InfoSphere Streams application deployment capabilities
  - Dynamic application composition
  - Operator placement
- InfoSphere Streams failover and recovery
  - Processing element recovery
  - Streams runtime services recovery

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4.1 Architecture, instances, and topologies

In this section, we discuss and describe the Streams runtime architecture, instances, and deployment topologies.

4.1.1 Runtime architecture

Much like database management systems and J2EE application servers, InfoSphere Streams has a runtime engine that Streams administrators define, configure, and run. The term Streams instance is used to refer to the software configuration executing on one or more hosts (servers) that provides an environment for Streams applications to be started, stopped, managed, and monitored.

A Streams instance consists of a number of service processes that interact to manage and execute the Streams applications. Separate Streams instances can be created and configured independently from each other even though they may share some of the same physical hardware.

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Figure 4-1 shows a Streams instance with its constituent services that will be described in the following sections.

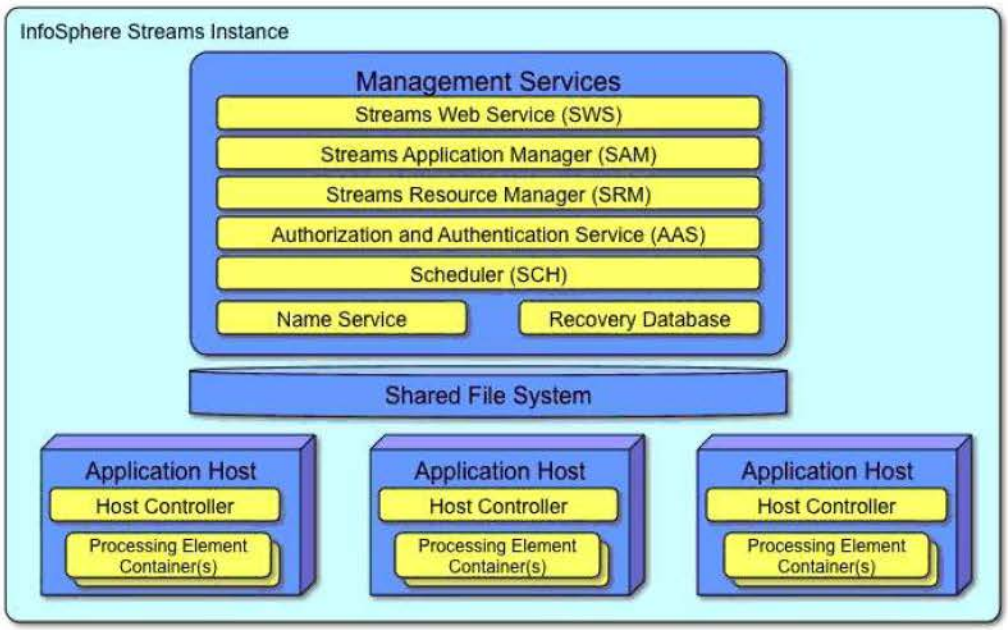


Figure 4-1 Services associated with the Streams instance

Management services

There is a single set of management services for each Streams instance. If the instance is instantiated on a single host, then all services will be run on that single host. If the instance is spread across multiple hosts, the management services can be placed on different hosts or co-located together on a single host. The management services include the following:

- Streams Application Manager (SAM)

  The Streams Application Manager is a management service that administers the applications in the Streams runtime system. The SAM service handles job management tasks, including user requests, such as job submission and cancellation. This service interacts with the Scheduler to compute the placement of processing elements (PEs) that are associated with an application. It also interacts with the Host Controller(s) to deploy and cancel the execution of PEs.

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- Streams Resource Manager (SRM)

  The Streams Resource Manager is a management service that initializes the Streams instance and monitors all instance services. SRM collects runtime metrics on the instance hosts and Streams components. This service also collects performance metrics that are necessary for scheduling and system administration by interacting with the Host Controller.

- Scheduler (SCH)

  The Scheduler is a management service that computes placement decisions for applications that are deployed in the Streams runtime system. The SCH service interacts primarily with the SAM service to handle job deployment requests, and with the SRM service to obtain the set of hosts that can be used for deployments. The SCH service also interacts with the SRM service to collect runtime metrics that are necessary for computing PE placement recommendations.

- Name service (NSR)

  The name service is a management service that stores service references for all the instance components. This service is used by all instance components to locate the distributed services in the instance so that Streams components can communicate with each other.

- Authentication and Authorization Service (AAS)

  The Authentication and Authorization Service (AAS) is a management service that authenticates and authorizes operations for the instance.

- Streams Web Service (SWS)

  The Streams Web Service (SWS) is an optional management service that provides web-based access to instance services. To use the Streams Console, SWS must be running on a host in the instance.

- Recovery database

  Streams instance recovery is an optional configuration setting. If recovery is configured, the Streams recovery database records the state of instance services. When instance management services fail, Streams restarts them and restores their state by retrieving the appropriate state data from the recovery database.

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Application host services

Application host services run on each host in a Streams instance that will be available to execute Streams applications. Those services include:

- Host Controller (HC)

  The Host Controller is an application service that runs on every application host in an instance. This service carries out all job management requests made by the SAM service, which includes starting, stopping, and monitoring PEs. This service also collects all performance metrics from PEs and reports the results to the SRM service.

- Processing Element Container (PEC)

  Streams Processing Language programs consist of operators, which are grouped at compile time into partitions. The execution container for a partition is a processing element (PE). Each partition runs in one PE. PEs are loaded by the Processing Element Container (PEC), which is started and monitored by the Host Controller for the host on which the PE is running.

Shared file system

A multihost Streams instances configuration requires a shared file system to share instance configuration information and SPL application binaries across the hosts.

Technologies used to implement a shared file system must be Portable Operating System Interface for UNIX (POSIX) compliant, and include, but are not limited to the following:

- Network File System (NFS)
- IBM General Parallel File System (GPFS™)

4.1.2 Streams instances

The Streams runtime environment is configured as a Streams instance. Each instance operates as an autonomous unit and can be configured with multiple options. In this section, we look at the most commonly used options for instances. For a complete set of options, refer to the *Streams Installation and Administration Guide* and the **`streamtool man command`**. You can find the guide at the following address:

`http://publib.boulder.ibm.com/infocenter/streams/v2r0/index.jsp`

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Each Streams instance is autonomous and isolated from other instances. You could create multiple instances on the same Streams installation, but this is not a best practice. Even though instances can share the same physical resources, there is no logical interference with other instances. (The use of multiple instances on the same set of physical resources can cause physical resource contention because the services for each instance are competing for the same CPU cycles and networking resources.) Streams SPL applications are run on an individual instance, and no other instances are aware of the jobs.

Streams instance IDs

A unique instance ID identifies each Streams instance within a Streams environment. The format of a fully qualified Streams instance ID is *instance-name@userid*, where instance-name provides a meaningful name for an instance to identify one from another in a multi-instance environment, and userid is the user name of the person who created the instance (instance owner). Note the use of the "@" character to separate the instance-name from the userid.

The instance-name must satisfy the following requirements:

- The name must be unique among the instances defined by you, the instance owner.
- The name must contain alphanumeric characters and start with an alphabetic character. Each of the alphanumeric characters must be one of the following ASCII characters: 0 - 9, A - Z, and a - z.
- The name can contain a dash (-), an underscore (_), or a period (.).

The following are examples of instance IDs that would be valid and unique in a multi-instance environment:

- streams@streamsadmin
- lab-inst01@streamsadmin
- stream_dev@mary
- stream_dev@john

Use the following guidelines when you use Streams instance IDs to specify Streams instances:

- The instance owner can use the full name of the Streams instance ID, or the just the instance name. The system will assume the userid is the user name of the current user.
- Users accessing an instance created by a different user must use the full name of the Streams instance ID (instance-name@userid), specifying the userid of the instance owner.

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Streams instance configurations

To make decisions about how many instances you will need, and how they will be configured, it is important to understand a couple of basic ways to categorize instances from a planning perspective. Streams instance configurations are characterized by configuration type and usage pattern or purpose. The configuration type is specified when you create a Streams instance, but the usage purpose will be chosen and governed by you.

Instance configuration types

Here are the two primary instance configuration types:

- Private instances

  Private instances are configured to only provide access to the instance owner. The instance owner is another term for the user that creates the instance. Private instances are easier to create and configure than shared instances, but they are not capable of supporting multiple users, and are not recommended for production use.

- Shared instances

  Shared instances allow a group of users to have access to a single instance. Access Control Lists (ACLs) are used to secure the instance and specify which users can administer the instance, and which users can submit and cancel jobs from the instance. Other than development instances, most instances should be created as shared instances.

Instance usage purpose

As you plan your Streams environment, you should plan to separate development activities, integration and test activities, and production operations into separate instances. Here are descriptions of those activities:

- Development instances

  Development instances are usually created as private (single user) instances, which use a single or small number of hosts. The primary purpose of these instances allows a developer to develop and test Streams applications, generic primitive operators, native functions, and so on.

  It is common for multiple development instances to share the same physical hardware.

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- Integration and Test instances

  Integration and Test instances are usually created as shared instances, which mimic a production environment. If separate Test and Integration instances are created, the Integration instance can use a smaller number of hosts than the production instance, but where possible, testing instances should provide an environment that is configured as much like the production instance as possible.

  The primary purpose of Integration and Test instances are to provide an environment where multiple users can run their applications in a single environment and verify adequate resource usage and availability, sharing of imported/exported streams, and cohabitation of applications.

  It is a best practice that Integration and Test instances be run on dedicated physical hardware.

- Production instances

  Production instances are primarily created as shared instances on a dedicated set of physical resources. These instances should be monitored for resource utilization to identify both CPU and I/O saturation.

Streams instance files

In addition to the runtime processes that make up a Streams instance, there are file system based components as well. Each Streams instance interacts with configuration, user authentication, and log files, which provide the persistent aspects of the instance.

Streams instance configuration files

The configuration information for each instance is stored in the `~/.streams/instances` directory of the instance owner ("~" is the Home directory in Linux). As configuration changes are made to the instance, these files are updated to persist the configuration.

Although instances are created using the tools from a Streams installation, instances themselves are separate from any Streams installation. If Streams is uninstalled, the instance configuration files remain untouched.

Each user's `~/.streams` directory should be backed up, and it is especially important to back up instance owners' `~/.streams` directories.

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Streams instance user authentication files

The public and private keys that Streams uses to authenticate Streams instance users are stored in either the default location of `~/.streams/instances/instance-name@userid/config/keys` or a directory configured by the instance owner. For more information, see "Configuring RSA authentication for Streams users" on page 169.

The authentication files should also be backed up on a regular basis.

Streams instance log files

When a Streams instance is active, both the runtime components and any running applications can generate log file content. Log files are located in `/tmp/streams.`*`instance-name@userid`*. This directory exists on each host that is part of the instance, but the contents of the directory will be different for each host, depending on what management services are executing on the host. Within this directory are two sub-directories: `logs` and `jobs`. The `logs` directory contains the logs for any management services running on the host. The `jobs` directory contains a separate directory for each job (for example, Streams application) that is currently executing on the host. Each of the jobs sub-directories contain the log files for the processing elements that is currently executing on that host.

When you stop a Streams application job, its corresponding log files are removed unless you use the collectlogs parameter the **`streamtool canceljob command`**.

All instance logs are removed when you stop an instance.

4.1.3 Deployment topologies

In preparation for planning a Streams runtime deployment, an understanding of different deployment topologies is necessary. In this section, we look at three of the most common topologies.

Single Host Topology

The simplest topology is of course, a single host computer running a single Streams instance. This is a configuration that is suitable for learning Streams, developing applications, and possibly running lower-volume production applications.

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Figure 4-2 shows this topology.

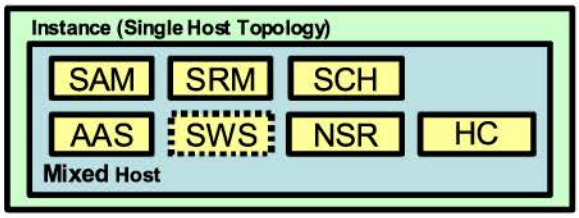


Figure 4-2 Single Host Topology

In a Single Host Topology, the host executes both the management services (SAM, SRM, SCH, AAS, NSR, and, optionally, SWS) and the application host services (HC and PEs when running an application). This type of host is referred to as a mixed host.

Configuration of a Single Host Topology is simplified because there are fewer *cluster* related setup and configuration steps required when preparing the operating system and environment.

This topology is well suited for single node VMWare Player/Workstation/Fusion installations.

Multi-Host Reserved Topology

The Multi-Host Reserved Topology is the most common and recommended topology for integration, test, and production environments. The *reserved* aspect of this topology refers to the usage of a single host for execution of the instance management services. This type of host is referred to as a Management Host.

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Figure 4-3 shows the Multi-Host Reserved Topology.

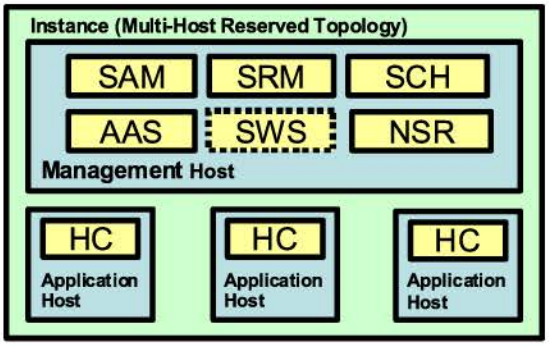


Figure 4-3 Multi-Host Reserved Topology

The additional hosts in this topology are configured to run the application host services, and are referred to as *application hosts*.

The advantage of this topology is the isolation between the management hosts and the applications hosts. Application hosts have dedicated resources for Streams application execution. In addition, a poorly written Streams application is not as likely to impact the stability of the entire instance. The management services are co-located on a single machine, and because all of the management services are required for the instance to be operational, it is considered a best practice to have a single point of failure, rather than multiple single points of failure.

The management services can be configured with a recovery database that allows them to be restarted on another host if they crash.

In environments with two to three hosts, the Host Controller (HC) service should be added to the management host to maximize resource utilization for applications that require it. This task can be accomplished by running **`streamtool addservice`**.

Multi-Host Unreserved Topology

The Multi-Host Unreserved Topology spreads the management and application host services across the nodes. In this configuration, most nodes are considered mixed hosts, although on large clusters there will be application hosts because there is a fixed number of management services.

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Figure 4-4 shows a sample Multi-Host Unreserved Topology.

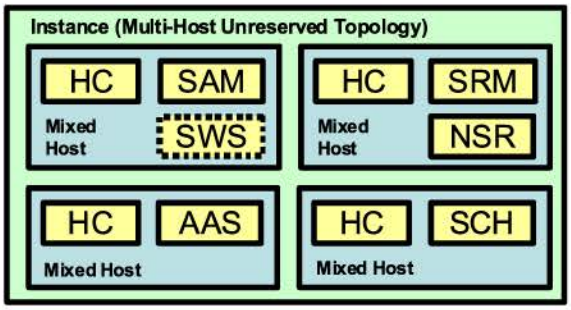


Figure 4-4 Multi-Host Unreserved Topology

This topology is not recommended for most configurations. It is found most commonly in environments where management service recovery is configured and the management services have been recovered onto different hosts.

Additional topology options

The Single Host and two multi-host topologies are examples of single instance topologies. If resources are limited, multiple instances can be configured to share resources. Figure 4-5 shows two instances running on a single host.

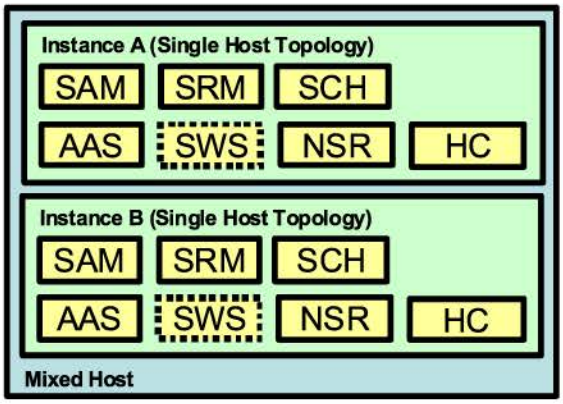


Figure 4-5 Single Host Multiple Instance Topology

Multiple instance topologies are typical in development environments. For more complex development environments, multi-host instances can be configured which share physical resources.

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4.2 Streams runtime deployment planning

In this section, we discuss the most common installation options you should consider when planning your InfoSphere Streams deployment. For a detailed list of all installation and configuration options, refer to the *Streams Installation and Administration Guide*.

The most important deployment options to identify and consider are:

- Streams Software Installation
  - Operating system version, configuration, and required packages
  - Streams software owner
  - Software installation directory (Streams and Eclipse)
  - Hosts to be configured for InfoSphere Streams usage
- Streams Instance Configuration
  - Streams administrator user (for shared instances)
  - Streams administrator home directory (Instance shared space)
  - Instance ID
  - Instance Administrative Group
  - Instance Users Group
  - Hosts assigned to the instance
  - Security Authentication Type
  - Instance Security Key Directory

4.2.1 Streams environment

There is a distinction between a Streams environment and Streams instances. A Streams environment is a set of one or more hosts that are capable of being part of an instance, but at any one time, the hosts may or may not be part of an instance. For example, you could install Streams on 10 hosts, and ensure all of the prerequisite and post-installation steps have been performed. At this point, you have a 10-host Streams environment.

The hosts in a Streams environment can be dedicated to a single instance, but in a development environment, they are often divided between a shared instance and hosts available to developers for private instances.

4.2.2 Sizing the environment

Part of designing a Streams system is sizing the hardware to determine the type and quantity of computers needed to support the envisaged applications with the necessary throughput and speed.

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Sizing the hardware for an undeveloped application is a difficult activity. You need to determine the amount of hardware required to execute the application, and which steps of the application are the most processor, network, and memory intensive. To do these task, you need to consider the following criteria:

- Volumes of data flowing in from the data sources, which includes average data rates and peak data rates.
- Estimated data reduction at various stages of processing. Wherever possible, you should reduce the data volumes by filtering, enabling you to only process data items that are relevant to the application.
- Complexity of the Streams operators. It is useful to assess, when possible, the processing requirement of the operators and processing flows within Streams. These requirements can be evaluated by prototyping and measuring the workload and resource usage of the prototype or by comparing it with Streams applications that have similar complexity.
- Model the total workload. You should scale the measured or estimated processing requirements by the projected workload volumes to give a projection of the processing requirement, that is, how many compute hosts are required to support the envisaged workload.

There is a trade-off as to whether you size a system to cope with average load, peak load, or somewhere in between:

- Sizing to the peak volumes means that you can achieve your throughput and latency targets more frequently, but the machines will be underutilized for periods of time.
- Sizing to the average throughput rate will result in less hardware than a peak volumes sizing, which results in an overall lower cost system. However, the latency of end-to-end tuple processing is likely to increase during times of above-average traffic, which will, of course, be undesirable in low latency focused systems.

4.2.3 Deployment and installation checklists

Before performing a Streams deployment, there are two types of checklists that should be created. In Table 4-1 on page 153, we provide an example of a Streams environment checklist. This checklist provides the information necessary when installing and configuring the Streams environment, but does not specify the options for any instances that will be defined in the environment. Table 4-2 on page 155 gives an example of a Streams instance configuration checklist. You should create one of these checklists for each shared instance that will be created in your Streams environment.

This section describes the options and values provided in these checklists.

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Note: There are many additional configuration parameters for Streams environments and instances beyond the options and values shown in this chapter. For more information, refer to the *Streams Installation and Administration Guide*.

Streams environment checklist

This section describes the options and values that you should organize before performing a Streams environment installation.

Table 4-1 is an example of a Streams environment checklist.

Table 4-1 Sample Streams environment checklist

Option	Sample value
Streams version	2.0.0.0
Streams Software Owner	streamsadmin
Streams Software Group	streams
Streams Admin Home Directory (Must be shared by all nodes.)	/home/streamsadmin
Streams installation location ($STREAMS_INSTALL)	/opt/streams/InfoSphereStreams
Eclipse installation location	/opt/streams/eclipse
Streams Installation Hosts	redbook1 - redbook14
Streams Available Hosts	redbook8 - redbook14

The options in this table are explained in the following sections.

Streams version

The options discussed in this book are based on Streams Version 2.0. Streams versioning is composed of {major}.{minor}.{release}.{patch}. Major interfaces and configuration options as described in here should not change with release or patch changes.

Streams Software Owner

The Streams Software Owner is the user account that will own the Streams software after installation. You should install the software as the root user. You supply the Streams Software Owner account as part of the install process (interactive, console, or silent).

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Streams Software Group

The Streams Software Group is the group that is assigned to the Streams software after installation. You will supply the group as part of the install process.

Streams Admin Home Directory

Your Linux administrator will most likely configure the Streams Admin Home Directory. It is important to know this location as it will contain a `~/.streams` (pronounced *dot streams*) directory. The `~/.streams` directory contains the Streams instance configuration files. If the same user account is used for the Streams admin and Streams software owner, then the `~/.streams` directory will also contain the Streams global configuration files. This directory should be backed up regularly.

Streams installation location

When installing Streams, you can set the location of the installed Streams files. During the install, you are prompted to specify the location. If you are performing the installation as the root user (suggested approach), the default location is `/opt/ibm/InfoSphereStreams`. If you do not have root authority, the default location is `<your home directory>/InfoSphereStreams`.

A best practice is to override the default location and select a directory that allows you to co-locate the Eclipse installation for Streams Studio, InfoSphere Streams, and any additional toolkits you install. See Figure 4-6 for a sample hierarchy. Note the use of a symbolic link to hide the version number. This action facilitates installing future versions that can be switched between by changing the symbolic link. All references should be made through the link (for example, `/opt/streams/eclipse`).

```
/opt/streams_2.0.0.0/
 InfoSphereStreams/   - Streams Installation Location
 eclipse/             - Eclipse Installation Location
 scripts/             - Your own scripts in this location
 toolkits/            - Additional Toolkits Location
/opt/streams -> /opt/streams_2.0.0.0 - Symbolic link
```

Figure 4-6 Sample Streams deployment directory structure

Eclipse installation location

The Streams IDE requires the Eclipse IDE framework. You have the option to use an existing Eclipse installation, or a new one.

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If you are using an existing Eclipse installation, this value should contain the file system path to that installation. You will not need this path during the installation of Streams, but it is still a best practice to capture this information for setting up users $PATH environment variables so that they run the correct version of Eclipse.

If you installing a new Eclipse framework for use with Streams, you should select a directory that allows you to co-locate Eclipse with Streams (Figure 4-6 on page 154 for a sample).

Streams Installation Hosts

The Streams Installation Hosts are the set of all of hosts that are going to be part of your Streams environment. Each of these hosts have InfoSphere Streams installed and configured to be available as part of shared and private instances.

Streams Available Hosts

The Streams Available Hosts are the hosts that you will make available to Streams users for developing applications and creating their own (that is, private) instances. Hosts that you will dedicate exclusively to a shared instance should not be contained in this list, as they will be specified when you define the shared instance.

Streams instance configuration checklist

This section describes the options and values that you should organize in preparation for the creation of a shared Streams Instance. Table 4-2 shows a sample instance configuration checklist.

Table 4-2 Sample instance configuration checklist

Option	Sample value
Streams Admin User (Usually the same as the software owner)	streamsadmin
Streams Admin Home Directory (Must be shared by all nodes,)	home/streamsadmin
Streams Instance ID	streams@streamsadmin
Streams Admin Group	streamsadmin
Streams User Group	streams
Shared Instance Primary (Management) Host/Server	redbook1
Shared Instance Secondary (Application) Hosts/Servers	redbook2 - redbook7

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Option	Sample value
Instance Shared Space	home/streamsadmin/.streams
User Shared Space	shared/data
Streams Name Service URL	DN: - Distributed Name Server (default)
Security Authentication Type	PAM (default)
Pam Enable Key	True (default)
Security Public Key Directory	home/streamsadmin/streams_keys

Streams Admin User

The Streams Admin User (also known as the instance owner) is the user account that will create and own your Streams instance. This user account should be the same as the Streams Software Owner. This user account can create multiple instances in a multi-instance topology.

You will not be prompted to specify this user account during the installation process, but you will use this account to create your instance.

Streams Admin Home Directory

Your Linux administrator will most likely configure the Streams Admin Home Directory. It is important to know this location as it will contain a `~/.streams` (pronounced *dot streams*) directory. The `~/.streams` directory contains the Streams instance configuration files. If the same user account is used for the Streams Admin and Streams Software Owner, then the `~/.streams` directory will also contain the Streams global configuration files. This directory should be backed up regularly.

Streams instance ID

The Streams instance ID is discussed in "Streams instance IDs" on page 144. This deployment option refers to a shared instance that will be created by the Streams Admin for use by multiple users.

Your deployment may have multiple instances. Some will be single-user developer instances that are somewhat transient, but likely you will have one or more shared instances.

Instances are not created as part of the installation. You will create them after installing the software.

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Streams Admin Group

This option is the name of the administration group to use during instance creation to initialize the access control list for shared instances. This group must exist in the authentication database before creating the shared instance.

Users in the administration group will have permissions to manage all configuration parameters and streams jobs in the instance. As an example, users in the admin group will be able to cancel jobs submitted by any user.

Streams User Group

This option is the name of the users group to use during instance creation to initialize the access control list for shared instances. This group must exist in the authentication database before creating the shared instance.

Users in the user group will have permissions to start, stop, and manage their own jobs in the Streams instance.

Primary (Management) Host / Server

The Primary host represents the server that will host the management services in a Multi-host Reserved Topology. If you are installing a single host instance, this will be the only host that your instance uses. In the case of a Multi-host Unreserved Topology, identifying a single node where you will execute commands from is a best practice.

Secondary (Application) Hosts / Servers

The Secondary hosts are the additional hosts that will be configured to be part of your Streams environment. Some of these hosts may be reserved for private developer instances and will not be part of your shared instance. In these cases, it is still important to identify these hosts because they do require Streams to be installed.

Instance Shared Space

The Instance Shared Space is the location where Streams Instance configuration files are located. In the current release of Streams, this location is located within the `~/.streams` directory of the Streams instance owner.

User Shared Space

The User Shared Space is file system storage that is shared across all hosts in a Streams instance. This space is usually in addition to the users home directories that are also are shared across the hosts.

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The primary purpose of this space is for application and toolkit development. Permissions are often opened up to include a development group for collaboration and sharing.

NFS is not the best choice for this space because of latency issues observed with NFS in a distributed computing environment. The IBM General Parallel File System (GPFS) is a low-latency, high performance, and highly distributed file system that works well for this purpose. It can use either extra local disks on the cluster hosts and it can also use SAN attached storage. GPFS is licensed and distributed separately from InfoSphere Streams.

Streams Name Service URL

This option is the URL for the name service the instance will use. This option provides a reference to either a distributed or file system based name service. The default is a distributed name service.

Specify 'DN:' to use the distributed name service. This is the best value if you are not configuring your instance for management service recovery.

Specify a value of 'FS:' to use the file system based name service. A default file path will be used unless a path is specified following the 'FS:'. The directory path must not contain white space characters. If you are configuring management service recovery, then you must specify the file system based name service.

Security Authentication Type

The run time's authentication processing integrates with the customer's existing user authentication infrastructure. Integration with Pluggable Authentication Modules (PAM) for Linux and Lightweight Directory Access Protocol (LDAP) back ends are supported. All user repository management occurs outside of InfoSphere Streams, directly using the back-end infrastructure's toolset.

The instance's authentication configuration is established when the instance is created. By default, the PAM back end is used. The PAM authentication defaults to a PAM service named *login*. To customize the name of the default PAM service for your installation, refer to the *Streams Installation and Administration Guide*.

The integration with PAM also enables use of a public/private key mechanism (created by the **`streamtool genkey command`**) to enable the construction of a secure environment where the user is not prompted to provide their password. To avoid password prompting for shared instances, the public key for users authorized to an instance should be copied to the directory identified by the SecurityPublicKeyDirectory instance configuration property. To disable the use of keys, specify `'--property PamEnableKey=false'` with **`streamtool mkinstance`**.

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PAM is the suggested authentication mechanism.

A security template that uses LDAP can be used if the installation owner has enabled LDAP. The --template ldap option can be used to specify LDAP authentication if it has been enabled. To configure the use of LDAP for your installation, refer to the *Streams Installation and Administration Guide*.

Security Public Key Directory

The Security Public Key Directory property is the PAM-specific property for Streams instances. Enabling RSA authentication for Streams users involves managing the user's public keys and storing them in the directory path that is specified in this property.

Attention: It is extremely important that access to the RSA public keys directory be restricted and that you ensure the secure management of the public keys. For more information, refer to the *Streams Installation and Administration Guide*.

The default locations for the RSA public keys are as follows:

- For a private instance, the default directory is:

  ```
  ~instance_owner/.streams/key
  ```

- For a shared instance, the default directory is:

  ```
  ~instance_owner/.streams/instances/instance_name/config/keys
  ```

In environments that support multiple shared instances with a single instance owner (for example, Instance Admin), it is common to create a single keys directory in the instance admins home directory and set the instance configuration parameter (SecurityPublicKeyDirectory) to point to this location when creating the instance. This action allows multiple instances to use the same set of keys and centralize the management of these keys. Access control can still be maintained at the instance level to limit users abilities on each instance.

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4.3 Pre- and post-installation of the Streams environment

In this section, we discuss the requirements and preparations that must be performed before installing InfoSphere Streams.

4.3.1 Installation and configuration of the Linux environment

In this section, we define Installation and configuration of the Linux environment.

InfoSphere Streams cluster

One of the most overloaded terms in recent years is the term *cluster* when referring to a set of computers configured to work cooperatively to accomplish tasks. There are several categories of clusters including, such as high availability (HA) clusters, load-balancing clusters, and compute clusters. InfoSphere Streams does not require any additional cluster hardware or software to be used in a clustered configuration.

InfoSphere Streams provides the functionality of a compute cluster for streaming-data applications. In addition, Streams provides high availability and load-balancing capabilities for Streams applications.

Hardware requirements

InfoSphere Streams V2.0 requires Intel/AMD x86 (32- or 64-bit) hardware platforms. No special hardware components are required.

For multi-node (cluster) configurations, the hosts must be connected to a local area network.

Linux operating system requirements

All IBM InfoSphere Streams hosts must be running a supported operating system and satisfy all Streams operating system-related requirements.

The supported Red Hat Enterprise Linux (RHEL) operating system versions for Streams Version 2.0 are:

- RHEL 5.3, 32-bit and 64-bit
- RHEL 5.4, 32-bit and 64-bit
- RHEL 5.5, 32-bit and 64-bit
- RHEL 5.6, 32-bit and 64-bit

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Streams V2.0 does not support other Linux operating systems such as CentOS or Fedora. If you are upgrading Streams from a previous release, you might need to upgrade your Red Hat Enterprise Linux operating system version.

If you are running Streams across multiple hosts, you must satisfy the following operating system requirements:

- All hosts in an instance must run the same operating system version and architecture. For example, all hosts in an instance can run Red Hat Enterprise Linux 5.5, 64-bit.
- Different instances can use hosts that do not run the same operating system version. However, the hosts must run the same operating system architecture. For example, one instance can use hosts that run Red Hat Enterprise Linux 5.4, 64-bit, and another instance in the same Streams installation can use hosts that run Red Hat Enterprise Linux 5.5, 64-bit.

Streams provides tools that help you to verify this requirement on single and multiple hosts:

- Before install, run the dependency checker script to verify requirements on individual hosts.
- After install, use the **`streamtool checkhost command`** to verify requirements on single or multiple hosts.

Red Hat installation and configuration

The standard Red Hat installation meets the requirements of InfoSphere Streams, but there are several installation options available as you perform the operating system installation. In addition, there are several post installation environment configurations that must be configured, such as DNS and Shared File System. In Table 4-3, we provide guidance for these options.

Table 4-3 Red Hat installation and configuration options

Topic	Installation options
Red Hat Version	RHEL 5.3, 32-bit and 64-bit RHEL 5.4, 32-bit and 64-bit RHEL 5.5, 32-bit and 64-bit RHEL 5.6, 32-bit and 64-bit
RAM	Minimum: 1 GB (possible but not ideal). The amount of RAM required by Streams will be dependent on the Streams applications that will be developed and deployed on the Streams hosts. Recommended: 8 GB +

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Topic	Installation options
SELinux	DISABLED[a] You should disable SELinux for your first Streams installation.
Linux Firewall	DISABLED Firewall protection is recommended at the perimeter of the Streams cluster. Firewalls between cluster nodes will introduce latency.
Character Encoding	UTF-8
File System Space	/opt minimum: 2 GB /opt recommended: 8 GB +
Networking	Each host must have full TCP networking capabilities (binding to non-reserved TCP sockets) that are available to programs running in user mode. When you create a Streams instance or add hosts to an instance, you cannot use localhost or any other host name or address that resolves to a loopback address (127.*.*.*). The name of the host returned by **hostname** must match an entry in the Linux name resolver, for example, DNS, LDAP, Yellow Pages, or /etc/hosts.
Common User Management System (for multi-host topologies)	The Streams software owner, instance administrators, and users must have consistent UIDs across all hosts in the cluster. A common user management system (for example, LDAP or NIS) is a best practice.
X Window System	An X Window System interface can be used so that Streams nodes can have the Streams Studio IDE enabled. The Streams Studio IDE must run on a host configured to run InfoSphere Streams.

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Topic	Installation options
Consistent & Reliable Host Resolution	Use a host name and resolution technology which ensures: ► Forward and reverse lookup consistent across the cluster of nodes. ► Each host must be resolvable to itself and the other nodes through the same FQDN or short names, but not a mix. ► Complications are introduced when the system host name is not completely aligned with local host files, NIS, LDAP, or DNS.
NTP	Ensure all nodes synchronize to the same time source.
Default Shell	A bash shell should be configured as the default shell for all Streams users.
Shared File System Space (for multi-host topologies)	Use a technology such as IBM GPFS or NFS.
VNC Server	VNC Server is the recommended approach for remote display from Streams hosts to a user workstation. VNC Server is available as part of the Red Hat installation.

a. Streams does support SELinux, but it should be disabled unless you are going to enable and configure Streams for SELinux.

User and group configuration

Before performing the Streams installation, you must create the Streams Software Owner and Streams Software Group that you identified in the Installation and Configuration Checklist in Table 4-1 on page 153. Your Linux administrator will be able to create these users and groups. You will be prompted for them if you perform the installation as the root user.

4.3.2 InfoSphere Streams installation

After you have configured your Red Hat Linux environment correctly, you are ready to install InfoSphere Streams and its prerequisite software packages on each of the hosts that will part of your Streams environment.

Perform the Streams installation on every host that will part of your Streams environment.

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Although it is possible to install Streams on a shared disk that is available to every host, this action should be avoided because any requirement to fetch a remote page of the binary during run time will be fighting with the network traffic of the Streaming application, which could lead to stalls in the data processing, potentially leading to a backup.

Refer to Appendix A, "InfoSphere Streams installation and configuration" on page 369 for detailed Streams installation procedures.

4.3.3 Post-installation configuration

After InfoSphere Streams has been installed on all of the hosts in your Streams environment, there are several post-installation tasks that are recommended or required before using Streams.

The recommendations in this section are based on real-world experiences deploying Streams clusters for development, integration, and production environments.

Verifying execution permission on /sbin/ifconfig

Recent security concerns have prompted Linux system administrators to harden and lock down most Linux installations. In some cases, access to the `/sbin` commands have been revoked from all users except for the ones with root authority.

Streams requires that instance administrators have execute permission on `/sbin/ifconfig`. If you cannot execute this command, have your Linux administrator grant all of your instance administrators execute permission. This task can be accomplished by running the following command:

```
# setfacl -mask -m u:streamsadmin:rx /sbin/ifconfig
```

Configuring the Streams environment variables

InfoSphere Streams provides the `streamsprofile.sh command` for configuring user's environment variables. In addition to the Streams environment variables, most users will need to have additional environment setup performed, including:

- Adding the Streams Studio IDE (Eclipse) command to their execution path ($PATH)
- Configuring the JAVA_HOME environment variable
- Adding Java commands to their execution path ($PATH)

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To avoid a situation where each user adds these items to their own startup scripts (for example, .bashrc), a user with root authority should create a single script placed in `/etc/profile.d` that will set up the Streams environment for any user logging into one of the Streams hosts. This script needs to be configured on every host in the Streams environment. The script shown in Example 4-1 is a sample based on the suggested deployment layout. Note that the default streams instance (streams@streamsadmin) is configured (see bold italic text) when the **`streamsprofile.sh command`** is sourced.

Example 4-1 Streams environment variables

```
#!/bin/bash
# /etc/profile.d/streams.sh
# Setup Streams environment for users
#
streams_path="/opt/streams"
streams_dir="InfoSphereStreams"
eclipse_dir="eclipse"
toolkits_dir="toolkits"

pathmunge () {
   if ! echo $PATH | /bin/egrep -q "(^|:)$1($|:)" ; then
      if [ "$2" = "after" ] ; then
         PATH=$PATH:$1
      else
         PATH=$1:$PATH
      fi
   fi
}

### InfoSphere Streams
# Setup default instance for users (remove -i option for streams
default)
source ${streams_path}/${streams_dir}/bin/streamsprofile.sh -i
streams@streamsadmin

### Toolkits, including non standard toolkits included with Streams
export
STREAMS_SPLPATH=${streams_path}/${streams_dir}/toolkits:${streams_p
ath}/${toolkits_dir}

### Streams Studio Eclipse
export ECLIPSE_HOME=${streams_path}/${eclipse_dir}
pathmunge ${ECLIPSE_HOME}
```


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```
### IBM Java
export JAVA_HOME=/opt/ibm/java-x86_64-60
pathmunge ${JAVA_HOME}/bin
pathmunge ${JAVA_HOME}/jre/bin

### Setup umask for Streams
umask 0002
```

Defining the Streams available hosts

As described earlier, there is a distinction between a Streams environment and Streams instances. Within a Streams environment, there are usually hosts that are exclusively used for shared instances and are not considered available for use in development or temporary instances.

In this section, you will define the set of hosts that are available for use by Streams users to create additional instances (for example, development instances). To use instances from the set of available hosts, the instance will be defined using the numHosts option. The number of hosts requested will be provided from the set of available hosts defined in this section.

The *Streams Installation and Administration Guide* defines a series of steps that the **`streamtool mkinstance command`** will use to determine the set of hosts that are available in the Streams environment as follows:

1. **`~/.streams/bin/streams_get_available_hosts`**
2. **`~/.streams/config/hostfile`**
3. **`~install_owner/.streams/bin/streams_get_available_hosts`**
4. **`~install_owner/.streams/config/hostfile`**

We suggest the following approach for creating the list of available hosts in your Streams environment:

- Do not list hosts that will be exclusively part of a shared instance as available. These hosts will be specified by name when creating the shared instance.
- Create a list of hosts in the Streams software owners `~/.streams` directory (`~install_owner/.streams/config/hostfile`) that lists the hosts that are not dedicated to a shared instance. Developers can use these hosts to create their own private instances.

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Example 4-2 contains a sample available hosts file based on the example used in this book. Lines that begin with a pound sign (#) are comments. The hosts are listed on separate lines along with the host tags that represent how they can be used.

Example 4-2 Sample available hosts file

```
# /home/streamsadmin/.streams/config/hostfile
# Our Streams environment
# redbook1 - redbook7 are exclusively used for
# streams instance streams@streamsadmin
# redbook8 - redbook14 are available
redbook8, execution, build
redbook9, execution, build
redbook10, execution, build
redbook11, execution, build
redbook12, execution, build
redbook13, execution, build
redbook14, execution, build
```

There are two predefined host tags:

- Build

  A build host is one that has tools such as compilers, linkers, and libraries that are necessary to build an SPL application. The SPL compiler uses one or more of these hosts when performing remote parallel builds.

- Execution

  An execution host can be used to run SPL applications. These are the hosts that can be included in a Streams runtime instance.

In addition to the two predefined host tags, you can apply additional host tags to the available hosts. These additional host tags can be used during application deployment design to help control operator placement on specific hosts. For more information about user defined tags and host placement, see 4.5.2, "Operator host placement" on page 184.

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You can test and verify your method for defining the available hosts by running **streamtool lsavailablehosts -v**. The -v option will include the location of the source of available hosts. Example 4-3 illustrates this situation in our test environment:

Example 4-3 Test environment

```
$ streamtool lsavailablehosts -v
The source location of the host information is
'/home/streamsadmin/.streams/config/hostfile'.
Host                    Tags
redbook8   build,execution
redbook9   build,execution
redbook10  build,execution
redbook11  build,execution
redbook12  build,execution
redbook13  build,execution
redbook14  build,execution
```

Configuring a shared file system space

Multi-host Streams instances depend on a shared storage space area that is accessible from each of the hosts that are part of the instance. You should use a shared file system with extremely low latency, such as IBM General Parallel File System (GPFS); NFS is sufficient for small installations (for example, two to four hosts).

In addition to the shared home directory file space, you should have a dedicated area for software development that has shared access to all members of the development team. Even if you are using a software configuration management system (as examples, Clear Case and Subversion), it is useful to have a shared area for test data, test applications, test results, and any other shared files required by your project.

4.3.4 Streams user configuration

In this section, we discuss the tasks that need to be performed to enable Streams users to interact with the environment. Streams users are defined as anyone who interacts directly with the Streams environment or a Streams instance. These activities include:

- Creating and configuring private or shared instances
- Managing and monitoring Streams instances
- Compiling and running Streams applications

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Configuring Secure Shell for Streams users

Streams requires the use of Secure Shell (SSH) without a passphrase for communications between hosts in both single and multi-host installations. Even in a single host environment, you need to configure the instance owners account so that it can perform an SSH connection back to the same host.

You can either set up SSH without a passphrase, or use a passphrase caching programs such as ssh-agent.

Example 4-4 shows the process to configure ssh without a passphrase on Linux systems.

Example 4-4 Configure SSH

```
$ cd ~/
$ ssh-keygen -t dsa
Generating public/private dsa key pair.
Enter file in which to save the key
(/home/streamsadmin/.ssh/id_dsa): <ENTER> TO ACCEPT DEFAULT
Created directory '/home/streamsadmin/.ssh'.
Enter passphrase (empty for no passphrase): <ENTER>
Enter same passphrase again: <ENTER>
Your identification has been saved in
/home/streamsadmin/.ssh/id_dsa.pub.
The key fingerprint is: 6e:72:23:80:55:ec:73:d1:7f:10:09:16:a7:71:61:0d
streamsadmin@redbook1

$ cd ~/.ssh
$ cat id_dsa.pub >> authorized_keys
$ chmod 600 *
$ chmod go-w ~
```

Configuring RSA authentication for Streams users

Using RSA authentication eliminates the need for users to enter a password when running Streams commands that require authentication. By default, instances are created with RSA authentication enabled. We suggest that all users have a Streams RSA key generated as part of user setup.

Each user needs to generate their own public and private keys using the following command:

```
$ streamtool genkey
```


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The **streamtool genkey command** generates the following two files and places them in the ~/.streams/key/ directory:

- Private key: username_priv.pem
- Public key: username.pem

The generated keys for a user are not instance-specific, and can be used for any Streams instance that is configured to enable RSA authentication.

Attention: Take extreme care to guard your private key, as you would a password. The file must be readable only by your user ID.

To configure your private instances, no additional configuration steps are required.

To configure a shared instance, work with the instance administrator to copy your public key to the path specified in the instance's SecurityPublicKeyDirectory property.

4.4 Streams instance creation and configuration

In this section, we discuss the steps used to create, start, and verify a shared Streams instance. In addition, we discuss how developers can create their own private development instances using the set of hosts in their environment that are not reserved for shared instances. The examples in this section are based on the sample deployment and installation checklists described in Table 4-1 on page 153 and Table 4-2 on page 155.

4.4.1 Streams shared instance configuration

A Streams shared instance can be created using any of the topologies discussed in 4.1.3, "Deployment topologies" on page 147. In this example, we define a shared instance using a multihost reserved topology.

The commands in this section should be performed as the instance administrator (often the same account as the Streams Software Owner account). In our example, this will be the *streamsadmin* account.

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The management host, application hosts, and boot logs

In a multi-host reserved topology, one host is identified as the management host and will run all of the management services of the instance. The commands to configure and interact with a Streams instance can be executed from any of the hosts in the Streams environment (including those that are not even part of the instance).

You should issue commands and perform the configuration on the management host because it will have the most information about the status of starting the instance. A boot log is created on each host in the instance and located in `/tmp/<instance name>@<instance owner>.boot.log` (for example, `/tmp/streams@streamsadmin.boot.log`). The boot log on each host contains the boot (or startup) log for the services that are running on that host. The boot log on the management host, therefore, will have the boot information for each of the management services and it will be most accessible to you if you are issuing the instance configuration and start commands on that host.

In a multi-host reserved topology, there are one or more application hosts. When you start an instance, the application hosts will have boot logs in `/tmp` with the same name as the boot log on the management host. The boot logs on application hosts will only show the log for starting the host controller service.

Specifying shared instance hosts

There are two common ways to define the specific hosts that will be part of your shared Streams instance using the **`streamtool mkinstance command`**:

1. Use the --hfile option to specify a file that contains the host names of the hosts to be included in the instance. The first host listed will be the management host.
2. Use the --hosts option to specify a comma-separated list of host names. The first host listed will be the management host.

Note: There are many additional options described in the *Streams Installation and Administration Guide* for host selection; however, we are presenting the most common for shared instances, which use a reserved topology.

We suggest using the first option, which simplifies the **`streamtool mkinstance command`**, while providing a single place to make changes if you need to remove and recreate the instance. We created the host names file shown in Example 4-5 for our shared instance:

Example 4-5 Sample mkinstance host names file (for use with the -hfile option)

```
# /home/streamsadmin/streams@streamsadmin_hosts
# List of hosts for shared instance: streams@streamsadmin
```


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```
# First host listed will be management host
redbook1
redbook2
redbook3
redbook4
redbook5
redbook6
redbook7
```

Instance host tags

In addition to simply specifying the hosts that are used in the instance, you have the option to apply host tags to any or all of the hosts in the instance. The tags are user-defined labels that can be used to identify capabilities, configurations, or any other differentiation feature of the hosts. These tags can be used during application design and deployment to control how operators are distributed and placed on hosts. For more information about user-defined tags and host placement options, see 4.5.2, "Operator host placement" on page 184. Example 4-6 shows a host file with tags applied to some of the hosts.

Example 4-6 Sample mkinstance host names file (to use with -hfile) with host tags

```
# /home/streamsadmin/streams@streamsadmin_hosts
# List of hosts for shared instance: streams@streamsadmin
# First host listed will be management host
redbook1
redbook2 --tags ingest,fpga
redbook3 --tags ingest,fpgs
redbook4 --tags dbclient
redbook5
redbook6 --tags sanstorage
redbook7 --tags sanstorage
```

Creating and populating the security public key directory

The run time's authentication processing integrates with the customer's existing user authentication infrastructure. Integration with PAM and LDAP back ends are supported. The product, in our current example, uses PAM authentication in this example because it is easiest to configure and maintain. All user repository management occurs outside of InfoSphere Streams, directly using the back-end infrastructure's toolset.

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The instance's authentication configuration is established when the instance is created. By default, the PAM back end is used. The PAM authentication default is configured to use a PAM service named *login*. To customize the name of the default PAM service for your installation, refer to the *IBM InfoSphere Streams Installation and Administration Guide*. It is located at the following URL:

http://publib.boulder.ibm.com/infocenter/streams/v2r0/topic/com.ibm.swg.im.infosphere.streams.product.doc/doc/IBMInfoSphereStreams-InstAdmin.pdf

Another PAM integration default is configured to provide for the use of a public / private key mechanism to enable the construction of a secure environment where the user is not prompted to provide their password. To avoid password prompting for shared instances, the public key for users, authorized to an instance, should be copied to the directory identified by the SecurityPublicKeyDirectory instance configuration property.

The following commands are used to create a public key directory in the stream administrators home directory:

```
$ mkdir /home/streamsadmin/streams@streamsadmin_keys
$ chmod 700 /home/streamsadmin/streams@streamsadmin_keys
```

Previously in this chapter, we showed you how to create a public key and private key for each Streams user using the **streamtool genkey command**. At this point, you need to copy the private key for each user that will be authorized to use the shared instance into the public key directory you just created. The streams instance administrator key must also be copied into the key directory. The following is an example of the commands required:

```
$ cp /home/streamsadmin/.streams/key/streamsadmin.pem
/home/streamsadmin/streams\@streamsadmin_keys
```

Note: Copy the key for every use that will be authorized to use this shared instance into the directory. Keys can be added at any time. They can even be added after the instance has been created and started.

Creating and starting the shared instance

After defining the instance hosts file and creating the security public key directory, it is time to create the shared instance.

The **streamtool mkinstance command** is used to create Streams instances. For complete information about all of the options, refer to the *Streams Installation and Administration Guide* and the output from the **streamtool man mkinstance command**.

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The following command creates the shared instance for our example:

```
$ streamtool mkinstance -i streams@streamsadmin --hfile
/home/streamsadmin/streams@streamsadmin_hosts --template shared
--property
SecurityPublicKeyDirectory=/home/streamsadmin/streams@streamsadmin_keys
--property AdminGroup=streamsadmin --property UsersGroup=streams
CDISC0040I Creating Streams instance 'streams@streamsadmin'...
CDISC0001I The Streams instance 'streams@streamsadmin' was created.
```

Note: Save this command in a script file for reuse and documentation.

After the instance has been created, you can start the instance using the following command:

```
$ streamtool startinstance -i streams@streamsadmin
CDISC0059I Starting up Streams instance 'streams@streamsadmin'...
CDISC0078I Total instance hosts: 7
CDISC0056I Starting a private Distributed Name Server (1 partitions, 1
replications) on host 'redbook1'...
CDISC0057I The Streams instance's name service URL is set to
DN:redbook1.mydomain.net:34875.
CDISC0061I Starting the runtime on 1 management hosts in parallel...
CDISC0060I Starting the runtime on 6 application hosts in parallel...
CDISC0003I The Streams instance 'streams@streamsadmin' was started.
```

Verifying the instance

After your instance has been started, there are several **streamtool** commands that can be used to manage and configure your instance:

```
streamtool (get/set/rm)property
streamtool (ls/add/rm)host
streamtool (add/rm)service
```

For a complete list of **streamtool** commands, run **streamtool man**.

The **streamtool getresourcestate command** is the best way to get a quick snapshot of the health of the services of an instance. In Example 4-7, we show the results of this command immediately after starting the instance successfully:

Example 4-7 Command results

```
$ streamtool getresourcestate -i streams@streamsadmin
Instance: streams@streamsadmin Started: yes State: RUNNING Hosts: 7
(1/1 Management, 6/6 Application)
Host            Status   Schedulable  Services
Tags
```


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```
redbook1        RUNNING  -          RUNNING:aas,nsr,sam,sch,srm,sws
redbook1         RUNNING  yes       RUNNING:hc
redbook2         RUNNING  yes         RUNNING:hc
redbook3         RUNNING  yes         RUNNING:hc
redbook4         RUNNING  yes         RUNNING:hc
redbook4         RUNNING  yes         RUNNING:hc
redbook4         RUNNING  yes         RUNNING:hc
redbook5         RUNNING  yes         RUNNING:hc
redbook6         RUNNING  yes         RUNNING:hc
```

4.4.2 Streams private developer instance configuration

In addition to interacting with a shared instance, your developers will want to perform development using their own private instance. This approach provides isolation from other developers; however, the overlap of development instances on hosts can lead to resource constraints. Therefore, private developer instances should be used for functional development and testing of Streams applications; however, performance testing should be performed on a shared instance with exclusively dedicated hosts.

Development instances are simplified versions of shared instances for use by a single user. They can use one or more hosts from the set of available hosts configured in your Streams environment.

The developer instance configuration template simplifies instance creation and provides many default values and properties. The most important aspects of the developer template are as follows:

- It creates a private instance using the creators private key to authenticate access.
- The Streams Web Service (SWS) HTTPS port is randomly chosen from those ports available when the instance is started.

Important: At this time, it is possible for a user to manually specify hosts that are being used by shared instances. Users should be encouraged to use the --numhosts option for creating instances.

The commands in this section can be performed by any Streams user account configured as described in 4.3.4, “Streams user configuration” on page 168.

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STREAMS_DEFAULT_IID environment variable

The **streamtool** commands allow the user to specify the instance to interact with by using the -i or --instance-id flags. If a user does not use this option, **streamtool** will use the value of the STREAMS_DEFAULT_IID environment variable to determine the instance to target with the **streamtool** command. In an environment where a shared instance is set up as the default instance ID, users should override the STREAMS_DEFAULT_IID if they are going to be working with a private developers instance rather than the shared instance. This action will reduce confusion if the instance option is accidentally omitted when using **streamtool** commands.

Creating a single host private developer instance

The **streamtool mkinstance** default for host selection is --numhosts 1. This option will select the first host from the available hosts configured for the Streams environment.

The following commands create and start a single host private developer instance on one of the available hosts configured in the Streams environment:

```
$ streamtool mkinstance -i streams@devuser --template developer
CDISC0040I Creating Streams instance 'streams@devuser...
CDISC0001I The Streams instance 'streams@devuser' was created.
$ streamtool startinstance -i streams@devuser
CDISC0059I Starting up Streams instance 'streams@devuser...
CDISC0078I Total instance hosts: 1
CDISC0056I Starting a private Distributed Name Server (1 partitions, 1
replications) on host 'redbook8.mydomain.net'...
CDISC0057I The Streams instance's name service URL is set to
DN:redbook8.mydomain.net:48643.
CDISC0061I Starting the runtime on 1 management hosts in parallel...
CDISC0003I The Streams instance 'streams@devuser was started.
```

If you need to specify the exact host on which to create the instance, you can use the --hosts parameter to specify the host by name. The following commands create and start a single host private developer's instance on host named redbook14:

```
$ streamtool mkinstance -i streams@devuser --template developer --hosts
redbook14
CDISC0040I Creating Streams instance 'streams@devuser...
CDISC0001I The Streams instance 'streams@devuser was created.
$ streamtool startinstance -i streams@devuser
CDISC0059I Starting up Streams instance 'streams@devuser'...
CDISC0078I Total instance hosts: 1
CDISC0056I Starting a private Distributed Name Server (1 partitions, 1
replications) on host 'redbook14'...
```


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```
CDISC0057I The Streams instance's name service URL is set to
DN:redbook14.mydomain.net:41656.
CDISC0061I Starting the runtime on 1 management hosts in parallel...
CDISC0003I The Streams instance 'streams@devuser was started.
```

Creating a multi-host private developer instance

In addition to single host instances, developers can create multi-host private instances as well. The --numhosts option allows the user to specify the number of hosts to be included in the instance. If this number is greater than 1, the instance will default to using a single reserved node for the management host, and the additional hosts will be application hosts. To maximize the number of application hosts, you can use the --unreserved option, which will place the host controller (hc) service on all nodes.

The following example demonstrates the creation of a multi-host private developer instance on four available hosts and configures them to all be used for running Streams applications. In addition, it shows the **streamtool lshosts command** that displays the host layout of the new instance:

```
$ streamtool mkinstance -i streams@devuser --template developer
--numhosts 4 --unreserved
CDISC0040I Creating Streams instance 'streams@devuser...
CDISC0001I The Streams instance 'streams@devuser was created.
$ streamtool lshosts -l -i streamsInstance: streams@devuser
Host                  Services                    Tags
redbook8              hc,aas,nsr,sam,sch,srm,sws
redbook9              hc
redbook10             hc
redbook11             hc
```

Note: If you specify a value for the --numhosts option that is greater than the number of available hosts, you will receive an error from the **streamtool mkinstance command**.

Creating a private developer instance using Streams Studio

In addition to the command-line interface, you can create instances from within Streams Studio. It is a best practice that shared instances be created using the command-line interface and that the scripts to create them are preserved. Developer instances, however, are good candidates for creation from within Streams Studio.

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In Figure 4-7, we select **Make Instance...** from the Instances folder within the Streams Explorer pane.

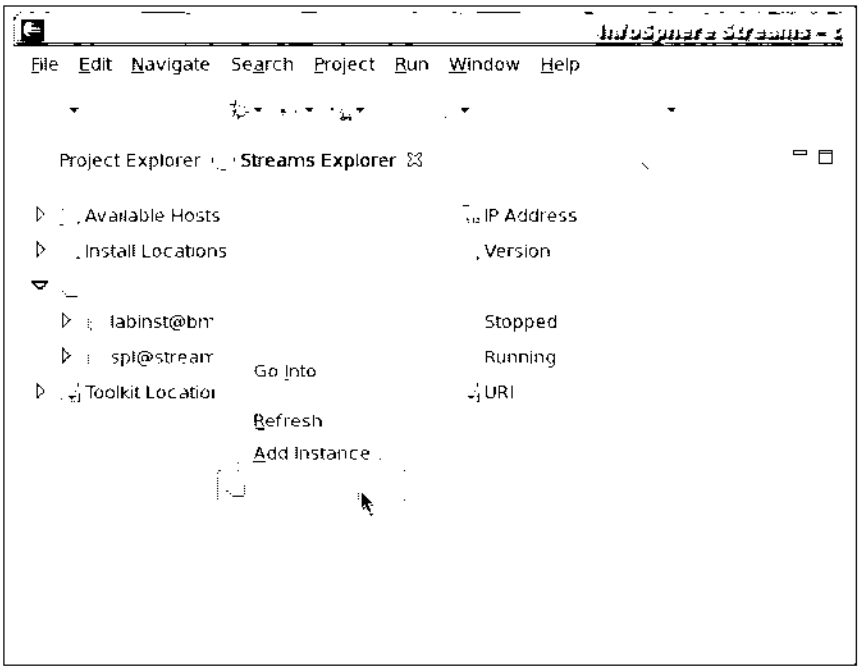


Figure 4-7 Streams Studio Make Instance menu

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Figure 4-8 shows the Make Instance window. It is important to select the **Use template:** option and the **Browse** button to select the developer template (developer.template.properties).

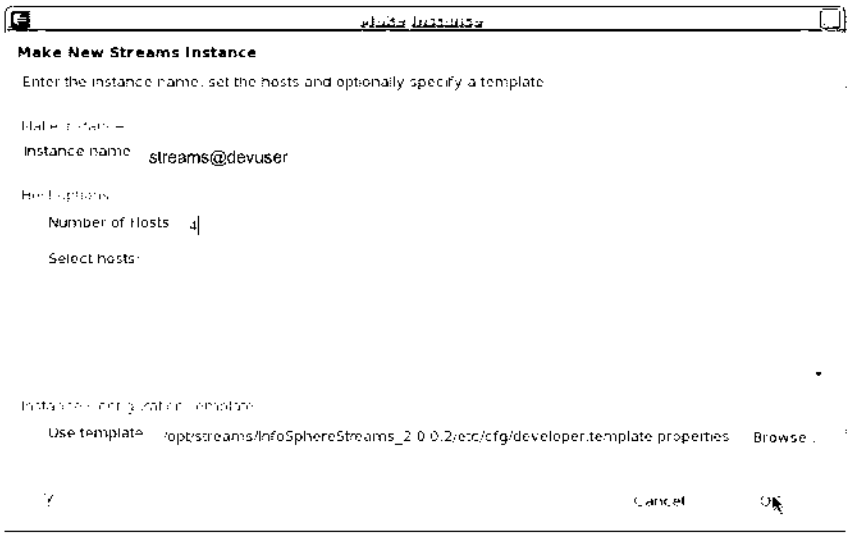


Figure 4-8 Streams Studio Make Instance window

After entering the instance name, number of hosts, and selecting the template, click the **OK** button. To start the instance, right-click the new instance within the Streams Explorer pane and select **Start Instance**.

At this point, you can use the instance from both Streams Studio and the command line.

4.5 Application deployment capabilities

In the first half of this chapter, we discussed Streams runtime deployment. We now focus on Streams application design and deployment. Having determined the topology, size, and layout of the runtime environment required for the projected applications (including their required volumes), you can determine how the processing should be divided across multiple hosts.

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Application deployment addresses the issue of how the components of the application are distributed and executed on the physical hosts. There are a number of ways that the application may be segmented and grouped to optimize throughput, latency and scalability:

- At development time
  - An application may be segmented into multiple applications. Then the data flowing through different streams within Streams may be exported from one application and imported into another application.
  - You may choose to deploy multiple copies of an operator, each working on a subset of the total stream. This allows parallel processing when the operator is processor intensive and cannot satisfy the throughput requirements on a single processor or host.
  - You may choose to segment processor-intensive analysis into multiple stages and then process the stream one stage after the other. This action allows pipelined processing and segmenting / distributing the processing load of the operators.
  - You may choose to control operator placement on the hosts of your instance. You can control operators that should be collocated, other operators that should not be collocated, and what set of hosts an operator may be allowed to run.
  - You may choose to manually combine multiple operators into a single Processing Element, which is called *fusing*. When operators are fused into PEs, they communicate through function calls and tuples are passed from one operator to the next using memory references, as opposed to using the transport (which may involve a transmission of the communication to take place across a network). Fusing can significantly reduce the cost of communication and improve both latency and throughput.
- At compile time

  Profile-driven fusion optimization is an approach in which the compiler will figure out how to best fuse operators into one or more PEs while respecting the user-specified constraints. This process is called *fusion optimization* and requires a profiling step where the application is first run in a profiling mode to characterize the resource usage with respect to CPU consumption and data traffic between each of the operators that make up the application.
- At run time
  - The Streams Application Manager (SAM) accepts requests to run applications. The SAM invokes the Scheduler service to determine which hosts the various PEs should run. The Scheduler then retrieves host information and performance metrics from the Streams Resource Manager, which enables the best placement of PEs to be determined dynamically at run time.

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– The PEs are deployed to the hosts as determined by the scheduler. The Host Controller on the hosts creates and manages a Processing Element Controller (PEC) to execute each PE.

The rest of this section discusses several of the application design and deployment capabilities that are available in InfoSphere Streams.

4.5.1 Dynamic application composition

The Streams run time allows you to run multiple applications in a Streams instance and export a stream from one application and import the stream into other applications. In Figure 4-9, we illustrate where the imagefeeder application (on the left) exports a stream of .jpeg images to the imagecluster, greyscaler, and imagewriter applications. In addition, this example illustrates streams data flowing from the imagecluster and greyscaler applications to the imagewriter application.

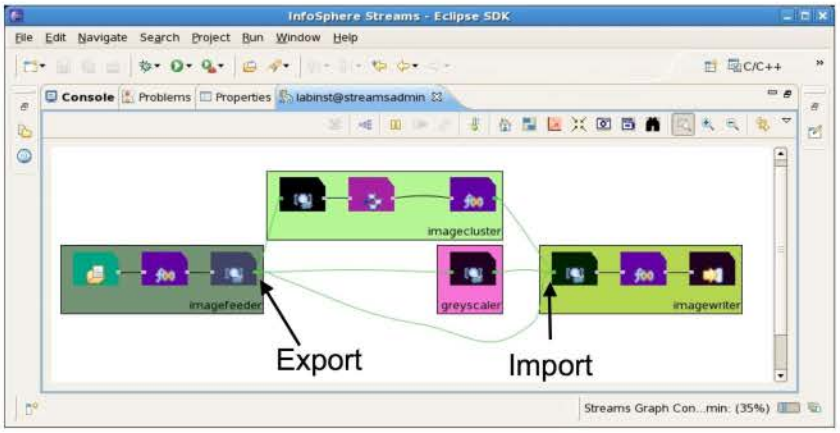


Figure 4-9 Application composition through Export and Import operators

The exporting and importing of streams between applications allows Streams administrators to use applications together to form larger integrated applications. On advantage of this approach is the ability to start and stop the individual applications independently without affecting the others. For example, you could choose to segment the Streams applications into three different categories, such as:

- Applications to read, validate and filter individual source streams.
- Applications to analyze a number of the source streams.
- Applications to format and deliver output data to sinks.

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This segmentation would allow Streams administrators to stop and start the source applications when the availability of Streams hosts varies. For example, you can run multiple analysis applications and develop and deploy new analysis algorithms without impacting the existing ones. You can also independently start and stop the sink applications to support new downstream applications to relieve load on the system when downstream applications are not active.

When exporting a stream from an application, you use the Export operator. When importing a stream into an application, you use the Import operator and then define which streams are being imported.

Exported streams and imported streams can be matched / connected in two different ways:

- Property-based application composition: This method uses a combination of stream properties that are set on the Export operator along with subscriptions specified on the Import operators. The middleware connects the imported and exported streams if the subscription predicate matches the exported stream properties and the stream schemas are compatible. If the Import predicate matches multiple streams exported by jobs running in the middleware, they are all connected. If there are no matching streams, nothing arrives at the Import operator. Properties and even subscriptions can be added, updated, or removed at run time.

  Example 4-8 shows property-based application composition:

Example 4-8 Property based composition

```
// imagefeeder application (partial listing)
composite imagefeeder {
  graph
    …
    stream<IplImage image,
           rstring filename,
           rstring directory> Img = ImageSource(Files) {…}

   () as ImagesExport = Export(Img) {
         param
           properties : { dataType = "IplImage",
                          writeImage = "true"};
    }
}
-----------------------------------------------------------
// imagewriter application (partial listing)
composite imagewriter {
  graph
    …
```


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```
    stream<IplImage image,
            rstring filename,
            rstring directory> ImagesIn = Import() {
          param
            subscription : dataType == "IplImage" &&
                           writeImage == "true";
    }
    …
}
```

- Application name and stream ID composition: This method requires the importing application to specify the application name and a stream ID of the Export stream. The exporting application uses the streamId property of the Export operator to identify the stream. The importing application uses the applicationName and streamID parameters of the Import operator to identify the specific stream to be imported. If the exporting application is defined within a namespace, the importing application must fully qualify the application name using the namespace and the application name. This approach to job integration is less flexible than property-based composition.

  Example 4-9 shows application name and stream ID composition:

Example 4-9 Application name and stream ID composition

```
// SensorIngest application (partial listing)
namespace projectA.ingest;
composite SensorIngest {
   graph
    …
    stream<uint32 sensorId,
          timestamp sensorTime,
          blob sensorData> SensorData = Functor(DataIn){…}

    () as SensorExport = Export(SensorData) {
      param
          streamId: "SensorIngestData";
    }

}

-------------------------------------------------------------
// SensorProcess Application (partial listing)
namespace projectA.processing;
composite SensorProcess {
   graph
    stream<uint32 sensorId,
```


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```
            timestamp sensorTime,
            blob sensorData> SensorData = Import(){
        param
          streamId : "SensorIngestData" ;
          applicationName : "projectA.ingest::SensorIngest";
      }
…

}
```

Note: If you export a stream from one application and it is not imported elsewhere, then the tuples in this streams are lost. They are not automatically persisted or buffered.

When you start an importing application, the contents of the stream are tapped from that point in time onwards. Likewise, if an importing application is stopped for a period of time and restarted, then the contents of the stream will be lost during the time the application is stopped.

4.5.2 Operator host placement

The Streams compiler and Scheduler are able to optimize your application by spreading the various operators (executed as processing elements known as PEs) across different hosts. By default, the Scheduler attempts to schedule hosts based on their current load.

In addition to automatic host placement, there is also the capability for you to manually allocate operators to specific hosts. You can also control which operators are placed on the same host, different hosts, and even specify which specific operators should be isolated and run on a dedicated host.

This section discusses the steps and artifacts involved in controlling operator host placement. For complete details, go to the following address:

http://publib.boulder.ibm.com/infocenter/streams/v2r0/index.jsp

Search for the section named SPL Config Reference.

Host tags

In “Defining the Streams available hosts” on page 166, we discussed host tags briefly, which included the two predefined host tags: build and execution. In addition to the predefined tags, the system allows you the ability to create your own tags and assign them to the hosts in your instance.

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The reason for defining host tags is to classify groups of hosts as having particular characteristics that a developer operator might need without specifying a specific host and restricting portability. Host tags are not required, but are a good idea if you are going to take manual control over operator placement.

In addition to assigning tags to hosts at instance creation, you can create host tags and assign them to hosts after the instance has been created, even while the instance is running. After an instance has been created, you use the **streamtool mkhosttag command** to define host tags. After defining tags, they can be assigned to hosts using the **streamtool chhost command**. Tags may be assigned to multiple hosts and a host may be assigned multiple tags.

Example 4-10 provides an example of defining, assigning, and displaying the host tags on a running instance.

Example 4-10 Host tags

```
$ export STREAMS_DEFAULT_IID=streams@streamsadmin
$ streamtool mkhosttag --description "Ingest Nodes" ingest
CDISC0102I Host tag 'ingest' has been added to instance
'streams@streamsadmin'.
$ streamtool mkhosttag --description "32GB RAM" himem
CDISC0102I Host tag 'himem' has been added to instance
'streamtool@streamsadmin'.
$ streamtool chhost --add --tags ingest,himem redbook2
CDISC0094I Adding host tags 'ingest,himem' to host 'redbook2' in
instance 'streams@streamsadmin'.
$ streamtool chhost --add --tags himem redbook3
CDISC0094I Adding host tags 'himem' to host 'redbook3' in instance
'streams@streamsadmin'.
$ streamtool lshosts -l
Instance: streams@streamsadmin
Host      Services                Tags
redbook1  aas,nsr,sam,sch,srm,sws  build,execution
redbook2  hc                      build,execution,himem,ingest
redbook3  hc                      build,execution,himem
redbook4  hc                      build,execution
redbook5  hc                      build,execution
redbook6  hc                      build,execution
redbook7  hc                      build,execution
```


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Host pools

Host pools are a collection of hosts defined in a Streams application that can be used to support operator host placement. There is always a default pool available, which by default consists of the complete set of hosts that are available in the instance and have not been allocated to exclusive pools. The size of the default pool can be limited through the use of the defaultPoolSize config directive or the -d Streams compiler option. These are defined in the config clause on the main composite for the application.

Host pools can be defined as shared or exclusive. A pool is shared if it can contain hosts that also appear in other pools. Conversely, a pool is exclusive if it must not contain any hosts that appear in other pools.

The hosts that are included in each host pool can be selected at run time in one of the two following ways:

- Tagged pool: Hosts included in this type of pool are allocated at run time from a set of hosts that been assigned a specific host tag or set of hosts tags.
- Implicit Pool: Hosts are allocated at run time from the set of hosts available in the instance the application is being deployed to that are not allocated to an Exclusive pool.

Although not recommended, a host pool may have the set of hosts assigned to it specified at compile time. In this case, the pool is defined by specifying the set of hosts by name or IP address at compile time. This is not recommended because it hinders deployment activities by tying the application to specific hosts and requiring a recompile if host assignments need to be modified in the future.

Host pools can be defined by providing a size, in which case, only the specified number of hosts will be selected at run time to be part of the pool. For example, if an instance has four hosts with a host tag of ingest, but the application defines a tagged pool based on the ingest tag with a size of 2, it will only include two of the four tagged hosts in the host pool. If a size is not specified in this example, then all hosts with the tag of ingest would be included in the pool.

Example 4-11 illustrates several host pool examples.

Example 4-11 Host pool examples

```
composite Main {
  graph
    // operator invocations here
  config
    hostPool :
      // Tagged pool, shared, no size specified
      ingestPool=createPool({tags=["ingest"]}, Sys.Shared),
```


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```
    // Tagged pool, exclusive, no size specified
    dbPool=createPool({tags["dbclient"], Sys.Exclusive),
    // Implicit pool, shared, sized
    computePool=createPool({size=2u}, Sys.Shared)
    // Explicit compile-time pool - NOT RECOMMENDED
    badPool = ["redbook2","10.5.5.10"];
```

Host placement configuration directives

SPL provides a config clause that allows developers to control the behavior and deployment of Streams operators. The placement operator config provides several subconfig options for controlling operator host placement.

There are two groups of host placement subconfigs:

- Absolute host location: This host subconfig specifies the absolute location (pool, IP address, or name) of the host on which the operator instance should run.
- Relative host constraint: These subconfigs constrain whether operator instances must run (hostColocation) or must not run (hostExlocation) on the same host, or whether they run in a partition that has a host of their own (hostIsolation).

placement : host

After one or more host pools have been defined, then you can specify if an operator instance should use a host from one of the host pools. If a runtime selected host pool is specified in the host config, then the actual host will be chosen at run time. This approach ensures maximum application portability. In addition to specifying a host pool, the host config can be used to specify an explicit host name or IP address, but this approach severely limits portability.

Example 4-12 illustrates examples of host config specifications.

Example 4-12 Host config specifications

```
composite Main {
  graph
    stream<int32 id> S1 = Beacon() {
      // System picks a host from the pool at runtime
      config placement : host (ingestPool);
    }
    stream<int32 id> S2 = Beacon() {
      // System picks host at a fixed offset from a pool
      config placement : host (ingestPool[1]);
    }
    stream<int32 id> S3 = Beacon() {
```


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```
    // System picks host by name !!Not Recommended!!
    config placement : host ("redbook1.mydomin.com");
  }
config
  // Tagged pool, shared, no size specified
  hostPool :
    ingestPool=createPool({tags=["ingest"]}, Sys.Shared);
```

placement : hostColocation

The hostColocation placement config allows you to specify a colocation tag. All other operator invocations that use the same collocation tag will be run on the same host.

placement : hostExlocation

The hostExlocation placement config allows you to specify an exlocation tag. Any other operator invocations that use the same exlocation tag must be run on different hosts.

placement : hostIsolation

The hostIsolation placement config allows you to specify that an operator must be run in an operator partition that has a host of its own. Other operators can be run in the same partition (refer to 4.5.3, "Operator partitioning" on page 189), but no other partition can be run on that host.

Note: There is potential for someone to erroneously specify inconsistent or conflicting config statements, making it impossible to resolve them completely. For example, exlocation can conflict with colocation. In most cases, the compiler can detect such conflicts, but in some cases it cannot. When the compiler detects a conflict, it issues an error message. If the compiler cannot detect conflicts, they will be identified when the application is submitted to run on an instance, resulting in a `streamtool submitjob` error.

In Example 4-13, we demonstrate the use of relative operator placement. In this example, all three operators will be placed on hosts from the ingestPool. There are, however, constraints that will require at least two hosts to be available in the pool. The operators that produce streams S1 and S2 will be collocated, and the operator that produces stream S3 cannot be located on the same host as S1.

Example 4-13 Relative operator placement

```
composite Main {
  graph
    stream<int32 id> S1 = Beacon() {
      // System picks a host from the pool at runtime
```


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```
    // and sets a colocation tag
    config placement : host (ingestPool),
                       hostColocation("withS1"),
                       hostExlocation("notWithS3");
  }
  stream<int32 id> S2 = Beacon() {
    // place this operator on the same host as the S1
    config placement : hostColocation("withS1");
  }
  stream<int32 id> S3 = Beacon() {
    // System picks host by name !!Not Recommended!!
    config placement : hostExlocation("notWithS3");
  }
config
  // Tagged pool, shared, no size specified
  hostPool :
    ingestPool=createPool({tags=["ingest"]}, Sys.Shared);
```

4.5.3 Operator partitioning

You can fuse multiple operator instances in an SPL application into units called *partitions*. Note that the notion of a partition of operator instances in the flow graph is distinct from the notion of a partition in an SPL window clause; they are unrelated concepts. The execution container for a partition is a processing element (PE). At run time, there is a one-to-one correspondence between partitions and PEs, because each partition runs in exactly one PE. Fusion is important for performance, because PE-internal communication is faster than cross-PE communication. Conversely, multiple PEs can use the hardware resources of multiple hosts. By default, the optimizer does not perform fusion and places each operator instance in its own PE. Furthermore, users can control fusion with explicit partition placement constraints in the code, as shown in Example 4-14.

Example 4-14 Operator partitioning example

```
int32 foo(rstring s, int32 i) { /*do something expensive*/ return i; }
//1
composite Main {
graph
  stream<int32 i> In = Beacon(){}

  stream<int32 i> A1 = Functor(In) {
    output A1        : i = foo("A", i);
    config placement : partitionColocation("A");
```


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```
    //fuse A1 into "A"
  }
  () as A2 = FileSink(A1) {
    param  file      : "A.txt";
    config placement : partitionColocation("A");
    //fuse A2 into "A"
  }
  stream<int32 i> B1 = Functor(In) {
    output B1        : i = foo("B", i);
    config placement : partitionColocation("B");
    //fuse B1 into "B"
  }
  () as B2 = FileSink(B1) {
    param  file      : "B.txt";
    config placement : partitionColocation("B");
    //fuse B2 into "B"
  }
}
```

4.5.4 Parallelizing operators

When you deploy your application on the runtime hardware, you may find that you have a single application operator, which is a performance bottleneck. This means that the operator cannot deliver the necessary throughput or perform all the required tasks within the required response time to satisfy the overall system performance requirements.

If you leave this operator unchanged, it will throttle the rate of throughput and require you to spread the workload over multiple hosts.

Parallelism of operators

One option to spread the workload is to segment the stream into a number of sub-streams, each of which can be processed in parallel on different host computers.

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Figure 4-10 shows this pattern.

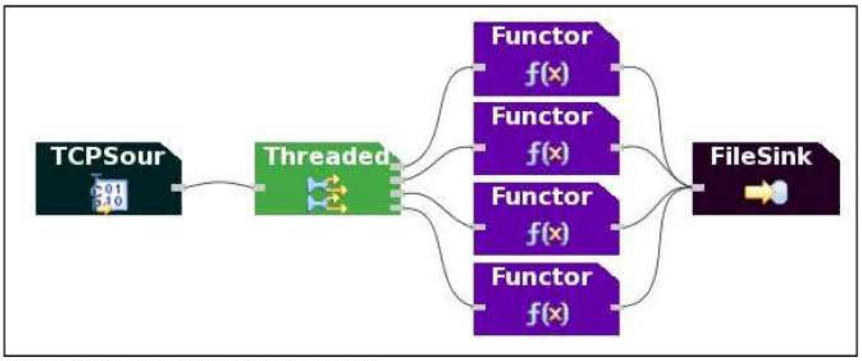


Figure 4-10 Parallel operator example

The problem of state

Stream computing works on the general principle that applications are stateless and that data passing through the system is not stored. However, a number of the Streams operators are not totally stateless, meaning they can be configured to keep state between subsequent tuples. When this is the case, splitting a stream for parallel processing can change the results of the operators.

The following list outlines the state management possibilities for the Streams operators:

- Tuple history: Expressions in parameters or output assignments of operator invocations can refer directly to tuples received in the past. History access maintains a list of tuples that can be subscripted by using the input port name.
- Operator windows: A window is a logical container for tuples recently received by an input port of an operator.
- Operator custom logic: The logic clause consists of local operator state that persists across operator firings and statements that execute when an input port receives a tuple or a punctuation and thus fires.
- Generic and Non-generic Primitive operators: User-written operators written in C++ and Java may have any number state mechanisms built into them. These are controlled by the operator developer and should be well documented.

You may want to segment a stream to distribute its workload, but be aware that this action can change the behavior of the stateful operators as they will now only receive a subset of the original stream.

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For example, consider a Join operator that joins data from multiple, high-volume streams. If these streams are segmented to distribute the processing load, the data items that would have matched in a single operator will be spread out over different join operators and the number of matches could be reduced.

Figure 4-11 shows an illustration of segmenting a Join operator:

- In the single join case, the operator processes three tuples (1,2,3) from both streams. Three matches will be output from the Join operator.
- In the split join case, the streams have been segmented and processed by three separate join operators. Only one of the tuple pairs will match in this case.
- In the partitioned join case, we have ensured that the streams are segmented to send related tuples to the same Join operator. All three matches will be identified and output in this case.

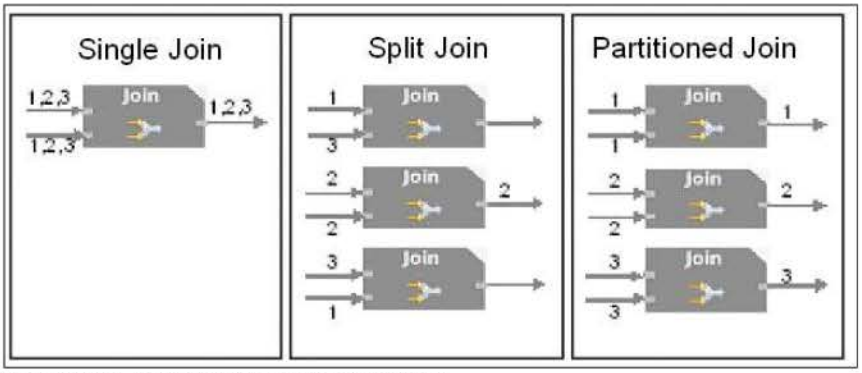


Figure 4-11 Parallel Join operator side effects

The use of partitioned windows can help when parallelizing operators. If you split the data using the windows partition key attribute, data will be kept together, preserving the integrity of partitioned window functions. For example:

- Consider the example of a stock trading application where you calculate the average price of a stock for each company in your portfolio. You can split the stock price stream by the stock symbol, as tuples will be kept together and your aggregate will be unaffected.
- In contrast, if you want to keep an average of all stock quotes together, segmenting the streams by the stock symbol will change the aggregate calculation.

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Pipelining as an alternative

An alternative to splitting a stream and processing in parallel is to use the pipeline pattern. With this option, processing is divided into multiple stages, which can be performed one after another.

Note that pipelining has larger communication requirements than parallelism. There is a processing impact and a time penalty in communicating between processing elements, especially when the PEs are on different hosts.

In the case of pipelining, every tuple is sent to every operator, so if you have five separate operators pipelined together, and each operator is executing on separate hosts, you have to send the tuples across all five hosts.

In contrast, if you segment a stream into five parallel operators, then each tuple only needs to be sent between hosts twice (once to the Parallel operator and then back again), but you incur a processing impact when segmenting the streams.

Parallel pipelining

The ultimate solution for many applications facing a performance bottleneck is to combine parallel processing with pipeline processing, resulting in parallel pipelines, as shown in Figure 4-12.

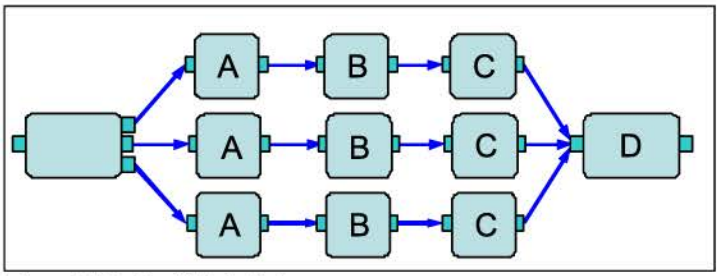


Figure 4-12 Parallel pipelining

The benefits of combining these two patters include:

- Tuples that require more processing (due to the size or complexity of the data) may slow down one pipeline. However, the other pipelines will still be processing tuples. This allows the faster tuples to pass the slower tuple as opposed to causing other tuples to clog up within the system.
- Each instantiation of the pipeline can be fused or at a minimum co-located on the same host, reducing network impact for each tuple. The set of instantiations of the pipeline can be distributed across a set of hardware, thus taking advantage of available resources.

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4.6 Failover, availability, and recovery

InfoSphere Streams provides a number of facilities to allow recovery from failed hardware and software components. Support for the following failure recovery situations is provided:

- The restarting and relocating of processing elements
- The recovery of failed application hosts (hosts running only the host controller and PEs)
- The recovery of management hosts (a host running any of the management services: SRM, SAM, SCH, AAS or NSR)

Recovery of application hosts and processing elements (PEs) do not require any additional instance configuration, but the extent to which processing elements can be recovered does depend on how they are configured within an SPL application.

Recovery of management hosts requires a recovery database (DB2 is required) and two changes to the instance configuration, that is, the recovery mode must be set to true, and you must use a file-system-based name service (NSR).

These recovery situations are discussed in the following sections.

4.6.1 Restarting and relocating processing elements

Recovery and relocation of stream processing applications has a few factors that can limit and even prevent recoverability and relocation, especially in a multi-host topology. For example, if operator A adds a counter to tuples that it processes, and operator B, which is down stream, depends on those counters continuing to increase, a restart of operator A that does not continue where it left off could adversely impact the logic and integrity of your application results. In another case, if operator C reads and writes information to a local (non-shared) file system, and Streams were to restart that operator on a different host, the file system may not exist or may not be in a configuration compatible with the operator. Therefore, this situation could cause further failure or invalid behavior.

The Streams runtime engine does not have insight into the internal workings of each operator, and it does not understand the dependencies between operators that have been built into your application (beyond the operator-to-stream connectivity). For this reason, the Streams run time takes a conservative view of processing-element recovery and relocation.

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By default, Streams assumes that an operator (and thus the processing element that contains it) cannot be restarted or relocated. It is up to you, the application developer, to provide configuration directives that tell Streams which operators can be restarted and which can be relocated.

To ensure that Streams can automatically restart restartable and relocatable PEs on a different host after a host failure, do not specify specific host names in the placement configuration section of your operators.

Restartable operator configuration

An operator instance can be restarted after a user-requested **`streamtool stopPE command`** completes or after a partition crashes due to a runtime error if it is marked as restartable in its config clause. In Example 4-15, we provide an example of a TCPSource operator that is being used in the role of a TCP server. We can mark this operator restartable because it does not contain a state, but we may not be able to make it relocatable because TCP clients may not be able to find it if it is restarted on a different host.

Example 4-15 Restartable example

```
stream<unit32 empid, float64 rate, float64 hours> payroll =
   TCPSource(){
   param
      role : server ;
      port : "55555" ;
      format : csv ;
   config
      restartable : true;
      relocatable : false;   // default
}
```

Relocatable operator configuration

An operator instance can be relocated on a different host, either after a failure or for better load balancing, based on relocation recommendations from the scheduler. The relocatable config implies the restartable config, but you may want to specify both for clarity.

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In Example 4-16, we provide an example of a TCPSource that is being used in the role of a TCP client. This operator can be both restarted and relocated without causing our application any problems. If, however, the network configuration of the environment has limited connectivity (through a firewall) to the TCP server and a limited number of hosts, you may not be able to relocate operators within this environment.

Example 4-16 Relocatable example

```
stream<uint32 empid, float64 rate, float64 hours> payroll =
   TCPSource(){
   param
      role : client ;
      address : "HRServer1.mycompany.com" ;
      port : "55555" ;
      format : csv ;
   config
      restartable : true ; // implied by relocatable : true
      relocatable : true;
}
```

Note: If an operator A is restartable and operator B is not, then A and B are partition-exlocated (meaning they cannot be in the same partition), unless the compiler option -O, --setRelaxFusionRelocatabilityRestartability is used.

Manual and automatic restart

Automatic restarting of processing elements are governed by the following three rules:

- Processing elements marked as restartable (but not relocatable) will be automatically restarted when they fail or crash if the application host they were running on is available.
- Processing elements marked as restarted and relocatable will be automatically restarted on the same host or a different host when they fail or crash.
- Processing elements not marked as restartable can only be restarted by canceling and resubmitting the application as a new job. If these types of PEs fail, the entire application must be cancelled and restarted.

Note: When a processing element or a Streams Job is restarted, entries in the data streams may be missed.

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In addition to automatic restart due to a failure, you can stop and restart processing elements manually. The automatic restart rules are still enforced (for example, you cannot restart a processing element manually that is not configured to be restartable). Manual processing element control can be performed using both the **streamtool** command and the Streams administration console. The following sub-commands are used through the **streamtool** command:

- **streamtool stoppe** is used to stop a specified processing element.
- **streamtool restartpe** is used to start a specified processing element on the same host or a different host.
- **streamtool lspes** is used to list the processing elements in the instance and is used to view their health and host assignments.

4.6.2 Recovering application hosts

Application hosts are hosts that are configured to run the Streams Host Controller (HC) service. The information in this section applies to Mixed hosts as well, because they also run a host controller. As discussed previously, the host controller service controls the execution of processing elements on a Streams host. If the host controller fails or stops responding, the SRM flags that the host cannot be scheduled. After a short period of time, the SAM changes the state of all PEs running on the failed host to Unknown. For example, if the state is *Running* when the HC fails, the state becomes *Unknown*.

The status of hosts in a running instance can be viewed using the **streamtool getresourcestate command**. The Schedulable column may contain the following values:

- A value of yes indicates that the host is available to run PEs.
- A value of "no" (and the *reason text* that is shown here) indicates that the HC service on the host is not functional and that any PEs on that host are in the Unknown state. The *reason text* indicates why the host is not available to run PEs.
- A dash (-) indicates that there is no HC service running or planned on the host.

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Figure 4-13 shows the results of the **streamtool getresourcestate command** after a host controller has failed on the specific host named *redbook6*.

```
$ streamtool getresourcestate
Instance: streams@streamsadmin Started: yes State: PARTIALLY_FAILED
Hosts: 7 (1/1 Management, 5/6 Application)
Host           Status    Schedulable  Services
redbook1       RUNNING   -            RUNNING:aas,nsr,sam,sch,srm,sws
redbook2       RUNNING   yes          RUNNING:hc
redbook3       RUNNING   yes          RUNNING:hc
redbook4       RUNNING   yes          RUNNING:hc
redbook5       RUNNING   yes          RUNNING:hc
redbook6       FAILED    no(failed)   FAILED:hc
redbook7       RUNNING   yes          RUNNING:hc
```

Figure 4-13 Failed application host

PEs in the *Unknown* state cannot be restarted automatically or with the **streamtool restartpe command**. However, they can be stopped with the **streamtool stoppe command**, but do not move to the Stopped state until the problem with the host controller has been resolved.

To repair a host that has a value of no in the Schedulable column, the administrator can perform the following actions:

- Restart the HC (**streamtool restartservice**): This command will attempt to restart the host controller service on the specified host. If the host controller does start, any PEs running on that host will move from the Unknown state to the Running state if they had not also failed.
- Quiesce the host (**streamtool quiecehost**): This command can only be performed if the host is not running a Streams management service. Quiesce performs a controlled shutdown of the PEs and the HC on a host. PEs will be relocated if possible. The host remains in the instance's configuration.
- Remove the host (**streamtool rmhost**): This command can only be performed if the host is not running a Streams management service. The command here performs a controlled shutdown of the PEs and the HC on a host. PEs will be relocated if possible. The host is removed from the instance's configuration.
- Remove the HC from the host (**streamtool rmservice**): This command will remove the host control (HC) from a host, which will prevent the scheduler from running PEs on that host. The PEs on that host will be relocated if possible. The Schedulable column shown as a result of the **streamtool getresourcestate command** will contain a dash (-).

In the last three cases, SAM will attempt to move restartable and relocatable PEs to other hosts. If SAM cannot move the PEs to other hosts, the PEs will remain in the Stopped state.

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4.6.3 Recovering management hosts

The default behavior of a Streams instance is to not allow the recovery of management services. In this default mode of behavior, if one of the instance's management services or hosts fails, you must restart your instance to restore it to a fully operational state.

One exception to this default behavior is the Streams Web Service (SWS). This service can be stopped or restarted without affecting the Streams instance or requiring special instance configurations.

To enable the recovery of any failed management services, Streams can work with an IBM DB2 database server to store the runtime data in a recovery database. For example, if a host is running the Streams Application Manager (SAM) server and the host crashes, the Streams instance administrator can restart the SAM server on another cluster host and the Streams run time will restore its state from the values stored within the recovery database.

Streams recovery database

The Streams recovery database is a DB2 database that records the state of an instance's services. If instance services fail, Streams restarts them and restores their state by retrieving the appropriate state data from the recovery database.

In addition, the Streams recovery database records information that enables the Streams instance administrator to manually restart the following management services, move these management services to another host, or both:

- The Streams Resource Manager (SRM)
- The Streams Application Manager (SAM)
- The Authentication and Authorization Service (AAS)

The information that is stored in the recovery database includes the following states for an instance and its applications:

- Job state
- Processing elements (PE) placement
- Stream connection state information
- Instance resource state (instance state, instance daemon placement, and state)
- Authentication and authorization state information

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A steady state is when all jobs are submitted and running and there are no changes to the state of the instance. The recovery database is not active when an instance is in the steady state. In addition, the recovery database is unaffected by the activity of Streams applications. This action prevents the configuration of failover and recovery from impacting the performance of Streams applications.

For details about configuring the Streams Recovery Database, see the *Streams Installation and Administration Guide*.

RecoveryMode instance property

In order to configure your instance to make use of the Streams Recovery Database, you must set the Streams instance property *RecoveryMode* to *on*. The following command will accomplish this task:

```
$ streamtool setproperty RecoveryMode=on
```

Note: If the instance is running when you set the RecoveryMode to on, you must restart the instance for the change to take effect.

File system based name service

By default, the NameServiceUrl property for a Streams instance is set to *DN:*, meaning a distributed name service is used. A distributed name service does not support a Streams recovery database. In contrast, it is a good idea to use a file system based name service when the recovery of management services is critical. To use a file system based name service, set the NameServiceUrl property to FS:.

Recovery process

If your Streams instance is configured with the RecoveryMode property set to on and you have configured a recovery database on one of your cluster's hosts, individual Streams management components can be recovered if they fail.

If more than one of these management services fail, restart them in the following order to ensure that any prerequisite service is already restarted:

1. SRM
2. AAS
3. SCH
4. SAM
5. SWS

You can view the status of all services using the **`streamtool getresourcestate command`**.

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To restart a service on the configured node, use the **streamtool restartservice command**. For example, to restart the SAM service, enter the following command:

```
$ streamtool restartservice sam
```

To move a service from one node to another node within the instance, use the **streamtool addservice command**. For example, to move the SAM service to the host named *hostname*, enter the following command:

```
$ streamtool addservice --host hostname sam
```


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5

Streams Processing Language

In the previous chapters, we have described Streams positioning, concepts, process architecture, and examples of the types of problems that can be solved by Streams.

In this chapter, we describe the language that is used to develop Streams applications and provide code examples related to real-world scenarios. More advanced features of the language, such as user-defined operators, are covered in Chapter 6, “Advanced Streams programming” on page 277.

To learn the intricate and extensive details about the Streams Processing Language, refer to the detailed set of documentation files shipped with the InfoSphere Streams product.

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5.1 Language elements

In this section, we describe the language elements that make up a Streams application. As a means to describe the elements of the language, we introduce a simplified example from within a mobile telecommunications company.

In this example, a mobile phone operating company is concerned about how their wireless infrastructure is performing. Customers have been complaining of calls dropping or the customer's lack of ability to make calls reliably. Consequently, the company is concerned that issues with cell broadcast masts may be impacting service revenues and customer satisfaction. Therefore, the company has built a Streams application to monitor calls and perform call re-routing around defective masts.

In Figure 5-1, we show an example Streams data flow for a mobile call re-routing application. Note that it consists of a number of operators, sources, sinks, and named flows (streams).

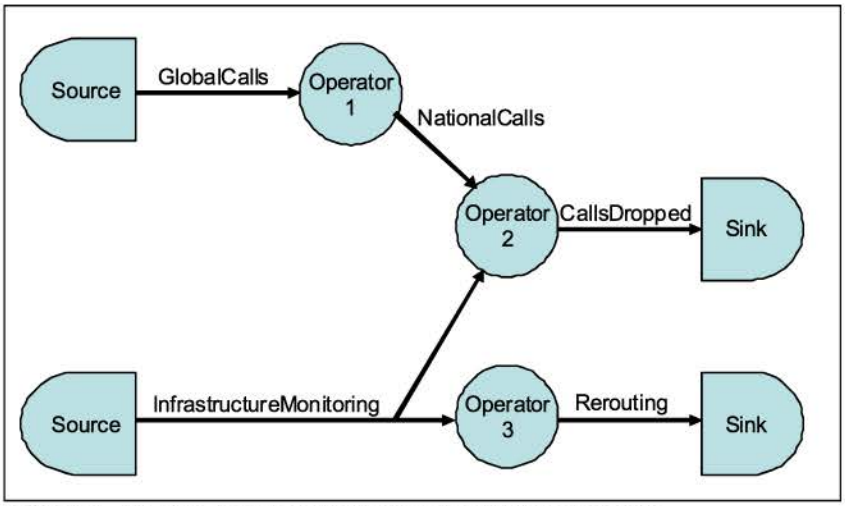


Figure 5-1 Example data flow for a mobile call re-routing application

The sources and sinks shown in the diagram are used by a Streams application to connect to outside data sources; they are the boundaries of the application as far as we are concerned. The Source operator reads information from an external input and the Sink operator writes the data to the external destination.

This Streams application is designed to receive real-time data feeds that are read by the two Source operators shown on the left side of the flow diagram.

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The input streams to the application provide:

- Data related to the calls being made by the company's customers in real-time (GlobalCalls)
- Real-time data related to the health of the company's transmission masts (InfrastructureMonitoring)

The customer call data stream is named GlobalCalls because that stream contains call data for calls irrespective of whether the customer is making the call while in the customer's home country or while abroad. Mast failure information, however, is available only from the masts located in the company's home country.

To avoid the impact of processing all the tuples in the GlobalCalls stream further on in the flow, the Streams application filters the GlobalCalls stream, removing any data from calls made on other countries' mast infrastructure. This filtering is performed in Operator 1.

It is not always possible to determine a call termination reason from the call tuples alone; the customer might have ended the call normally or the call might have been ended due to being interrupted by a fault. For example, a fault could have come from the mast being used while the call is active. Operator 2 correlates the call data coming in through the National Calls stream with the mast-health-monitoring information in the InfrastructureMonitoring stream to determine which calls were terminated specifically due to an infrastructure issue.

Operator 3 contains an internal re-routing table and, on the basis of failures, sends re-routing commands to the lower output sink.

In the Streams Processing Language, the flow described above would be expressed at a high level, as shown in Example 5-1.

Example 5-1 Expressing the data flow in Streams Processing Language

```
stream <...> GlobalCalls = TCPSource() {...}
stream <...> NationalCalls = operator1(GlobalCalls) {...}
stream <...> InfrastructureMonitoring = TCPSource() {...}
stream <...> CallsDropped = operator2(NationalCalls;
InfrastructureMonitoring) {...}
stream <...> Rerouting = operator3(InfrastructureMonitoring) {...}
() as CallsDroppedSink = FileSink(CallsDropped) {...}
() as ReroutingSink = FileSink(Rerouting) {...}
```


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Note that each stream is first defined on the left side of an assignment (an assignment is represented by the equals sign, "=", in Streams). Immediately following the "=" assignment is the operator name responsible for producing that stream.

Also note that both the source and sinks are also considered operators. Sources read from external sources and convert the data from an external representation to the Streams representation. Similarly, sinks do the reverse, meaning that the Streams internal format is converted to an external representation within a sink.

In Figure 5-1 on page 204, there is no stream shown beyond the sink; processing that occurs outside the source and sink is outside the scope of the Streams Processing Language.

The end of a flow is denoted with the "()" code syntax (instead of a named stream), as shown in the first two characters of the last line of Example 5-1 on page 205.

Note that within the parentheses, immediately following the operator name, is the list of one or more streams that are inputs to that operator. For example, in the sample code shown, 'GlobalCalls' is the input stream to operator1.

Also, note that the code example contains two types of braces: "() and {}". The contents of the braces will be elaborated later in this chapter, but at a high level might contain stream metadata, operator input arguments, operator parameters, and operator output attribute derivation expressions.

5.1.1 Structure of an SPL program file

Streams Processing Language files (source files) are ASCII text files that commonly have a ".spl" extension. As text files, they can be written and edited using any text editor of your choice, but most commonly are developed and maintained using the InfoSphere Streams Studio editor. Source files are compiled into binary code files using the supplied Streams compiler.

Tip: If you prefer to use a text editor rather than the Streams Studio to edit your Streams source files, syntax highlighters for vi, JEdit, and GNU emacs text editors are provided with the software.

Each `.spl` file commonly expresses a flow from source(s) to sink(s) through one or more operators connected by named streams.

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The Streams Processing Language supports comments. Single line comments are prefixed by the "//" character string combination. Anything after these characters, meaning from these characters to the end of the line, is ignored by the compiler. If comments are required to span multiple lines, the start of the comment section should be preceded by "/*" and ended with "*/".

Each source file is composed of up to six sections, of which two are mandatory. The six sections that are headed using square braces as follows:

1. Namespace
2. Use
3. Composite
4. Type
5. Graph
6. Config

The composite and graph sections are mandatory. As such, they are described together. The other sections are optional and will be discussed subsequently.

- Composite and graph

  A simple `.spl` file containing the mandatory sections is shown in Example 5-2.

Example 5-2 A sample .spl file for the re-routing application

```
// Call Re-routing application
composite Routing
   graph
      stream <...> GlobalCalls = TCPSource() {...}
      stream <...> NationalCalls = operator1(GlobalCalls) {...}
      stream <...> InfrastructureMonitoring = TCPSource() {...}
      stream <...> CallsDropped = operator2(NationalCalls;
InfrastructureMonitoring) {...}
      stream <...> Rerouting = operator3(InfrastructureMonitoring)
{...}
      () as CallsDroppedSink = FileSink(CallsDropped) {...}
      () as ReroutingSink = FileSink(Rerouting) {...}
```

Following the composite keyword is the name of the application (Routing in this example) which is followed by a keyword that indicates the beginning of the application sub-graph.

Following the keyword of `graph` is the body of the code. In this case, we have inserted the code from the prior example (which is incomplete at this stage, as evidenced by the ellipses).

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- Namespace

  At the top of the `.spl` program file, the developer can specify an optional namespace keyword followed by a namespace for the composite, as shown in Example 5-3. The presence of a namespace allows the application developers to avoid collisions between two different SPL composites that carry the same name.

Example 5-3 Namespace

```
namespace com.ibm.sample.regex;
```

- Use

  Following the optional namespace keyword, developers can optionally declare other composites and types that are used within this `.spl` file. The "Use" section allows the developers to improve the code readability by not expanding the fully qualified name for the external types and composites that are used in the `.spl` file. As an example, a developer could define a "use" statement to indicate that an external composite will be used later in the code section of this `.spl` file, as shown in Example 5-4.

Example 5-4 Use

```
use
com.ibm.streams.myUtils::FileWriter;
```

- Type

  Inside a composite, developers can optionally declare all the different data types that will get used in the SPL application. In this section, user-defined types, constants, and full-fledged tuple types can all be defined. Example 5-5 shows how such types can be defined.

Example 5-5 Type

```
type
   employeeSchema = tuple<rstring name, uint32 id, uint16 age,
float32 salary, rstring location>;
   myIntegers = list<int32>;
   expression <rstring> $RSTRING_FILE_MODE : "w+";
```


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- Config

  The SPL language allows for an extensive set of configuration directives that can either be applied at the individual operator level or at the composite level. These configuration directives range in functionality from assigning a default node pool size, providing a list of host pools, setting the level of logging, determining whether a PE should be restarted or not, establishing a threaded port for an input port with an optional queue size, fusing multiple operators, co-locating multiple operators on a specific host, ensuring two operators are not placed on a same host, and so on. Some of these SPL configuration directives are shown in Example 5-6.

Example 5-6 Using SPL configuration directives

```
config
   logLevel: info; // Log level verbosity increases in this order':
error, info, debug, trace
   placement: host("myhost.acme.com");
   restartable: true;
   relocatable: true;
   threadedPort: queue(Port1, Sys.Wait, 1500);
```

5.1.2 Streams data types

In this section, we describe the data types supported by Streams.

A stream has an associated schema, which is the particular set of data types that it contains.

A schema consists of one or more attributes. The type of each attribute in the schema may be selected from one of the following high-level categories:

- Primitive types
- Composite types

These categories are further described below:

- Primitive types

  The following primitive types are supported:

  - boolean: True or false
  - enum: User-defined enumeration of identifiers
  - intb: Signed b-bit integer (int8, int16, int32, and int64)
  - uintb: Unsigned b-bite integer (uint8, uint16, uint32, and uint64)
  - floatb: b-bit floating point number (float32 and float64)

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- decimalb: Decimal b-bit floating point number (decimal32, decimal64, and decimal128)
- complexb: b-bit complex number (complex32 and complex64)
- timestamp: Point in time, with nanosecond precision
- rstring: String of raw 8-bit characters
- ustring: String of UTF-16 Unicode characters
- blob: Sequence of raw bytes
- string[n]: Bounded length string of at most n raw 8-bit characters

- Composite types

  InfoSphere Streams provides two kinds of composite types. They are called built-in collection types and tuple types.

  The following are the three built-in collections, which can be either bounded or unbounded, making a total of six actual types as follows:

  - list<T>: A list of random access zero-indexed sequence of SPL types
  - set<T>: Unordered collection without duplicates
  - map<K,V>: Unordered mapping from key type K to value type V
  - list<T>[n]: list<T> with a bounded length
  - set<T>[n]: set<T> with a bounded length
  - map<K,V>[n]: map<K,V> with a bounded length

Another kind of composite type is a tuple, which is a sequence of attributes also known as named value pairs. For example, the tuple {name="aname", age=21} has two attributes, specifically name="aname" and age=21. The "type" for this tuple is tuple<rstring name, uint32 age>. Tuples are similar to database rows in that they have a sequence of named and typed attributes. Tuples differ from objects in Java or C++ in that they do not have methods. You can access the attributes of a tuple with dot notation. For example, given a tuple t of type tuple<rstring name, uint32 age>, the expression t.name yields the name attribute's value. Attributes within a tuple type are ordered.

5.1.3 Stream schemas

The data types may be grouped into a schema. The schema of a stream is the name that is given to the definition of the structure of data that is flowing through that stream.

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For the simplified call routing application, the GlobalCalls schema contains the following attributes:

- callerNumber: uint32, // the customer number
- callerCountry: uint16, // the country code where the customer is located
- startTimeStampGMT: rstring, // call start time
- endTimeStampGMT: rstring, // call end time
- mastIDs: list<uint32> // list of mast(s) used to make the call

Note that mastIDs is a list<uint32>attribute. In the example, it is assumed that each mast in the network has a unique numeric identifier. The mastIDs attribute contains a list of the mast identifiers associated with the set of masts used to process the customer's call.

Within the Streams application code, the schema of a stream can be referred to in several ways. Consider the following:

- The schema may be explicitly listed.

  The schema can be fully defined within the operator output stream parameters, as in schema fully defined in operator output stream, which shows the GlobalCalls schema, as shown in Example 5-7.

  Example 5-7 Schema fully defined in the operator output stream

```
stream <int32 callerNumber, int16 callerCountry, rstring
startTimeStampGMT, rstring endTimeStampGMT, list<uint32> mastIDS>
GlobalCalls = TCPSource() {...}
```

- The schema may reference a previously defined type.

  The schema definition can be created ahead of the operator definitions in the type section of the SPL program file. In the type section, Streams developers can associate a name with that schema and subsequently refer to that name within the code rather than the entire definition in full each time, as shown in Example 5-36 on page 258.

  In Example 5-8, the schema is given the name callDataTuples, which is then referred to in the definition of the GlobalCalls. Note that it is also possible to define a schema by referencing a previously defined stream.

  Example 5-8 Defining the tuple in the type section

```
callDataTuples = tuple<int32 callerNumber, int16 callerCountry,
rstring startTimeStampGMT, rstring endTimeStampGMT, list<uint32>
mastIDS>;

..
```


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```
..
stream <callDataTuples> GlobalCalls = TCPSource(...){...}
```

- The schema may be defined using a combination of the previously described methods.

  The last variant is that a schema for a stream may be defined by a combination of the methods, as shown in Example 5-9. In this example, another attribute is being added to the list of attributes already present.

Example 5-9 Defining a stream schema using a combination of methods

```
type
callDataTuples = tuple<int32 callerNumber, int16 callerCountry,
rstring startTimeStampGMT, rstring endTimeStampGMT, list<uint32>
mastIDS>;

graph
stream <callDataTuples, tuple<int32 anotherAttribute>> = ...
```

Where required, streams of the same schema may be collected together on a single input port of any operator.

5.1.4 Streams punctuation markers

InfoSphere Streams supports the concept of punctuation marks, which are markers inserted into a stream. These markers are designed in such a way that they can never be misinterpreted by streams as tuple data. Some Streams operators can be triggered to process groups of tuples based on punctuation boundaries or they can insert new punctuation marks into their output stream(s).

5.1.5 Streams windows

In previous chapters, we have described the need for accessing data through "windows" on the stream. Conceptually, we are working on streams of data that have no beginning or end. However, the streams operator's processing might need to group sections of the data stream within similar attributes or time intervals. The Streams Processing Language enables this type of grouping using a feature called windows.

Streams can be consumed by operators either on a tuple-by-tuple basis or through windows that create logical groupings of tuples.

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Windows are associated and defined on the input streams flowing into particular operators. If an operator supports windows, each stream input to that operator may have window characteristics defined. Not all Streams operators support windows; this is dependant on the operator's functionality. (For details about the windowing support in Streams, read the "Window Handling" chapter in the `SPLToolkitDevelopmentReference.pdf` file that is shipped with the Streams product.)

The characteristics of windows are as follows:

- The type of window
- The window eviction policy
- The window trigger policy
- The effect of adding the partitioned keyword on the window

These characteristics are described in the following sections:

- The type of window

  Two window types are supported, namely tumbling windows and sliding windows.

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– Tumbling windows

In tumbling windows, after the trigger policy criteria is met, the tuples in the window are collectively processed by the operator and then the entire window contents are discarded, as shown in Figure 5-2.

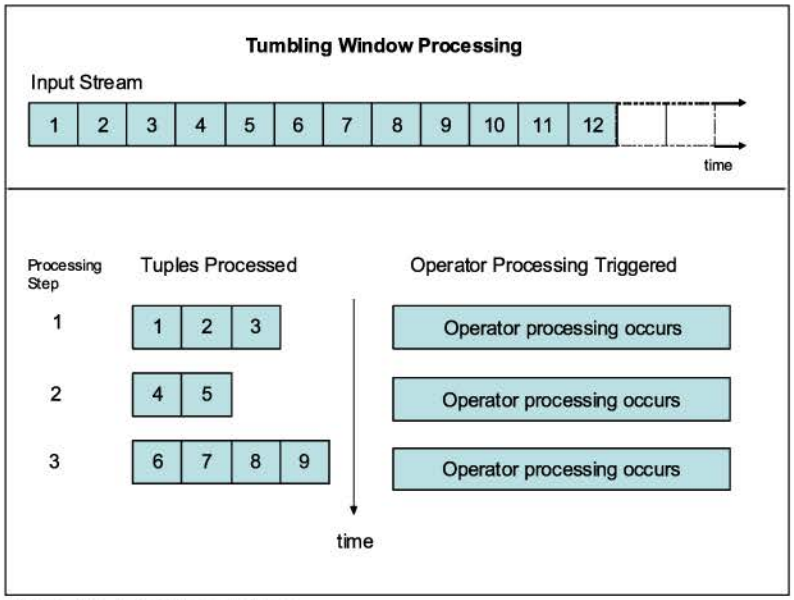


Figure 5-2 Tumbling windows

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– Sliding windows

  In sliding windows, newly arrived tuples cause older tuples to be evicted if the window is full. In this case the same tuple(s) can be present for multiple processing steps, as shown in Figure 5-3. In contrast to tumbling windows, with sliding windows any given tuple may be processed by an operator more than once.

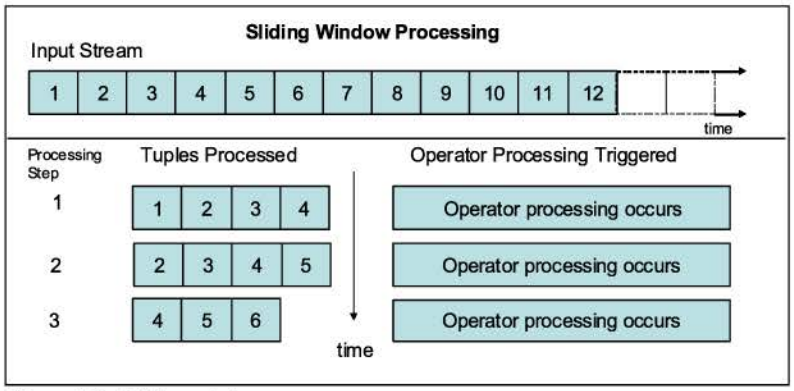


Figure 5-3 Sliding windows

- The window eviction policy

  The eviction policy is what defines when tuples are removed from the window. The eviction policy may be specified, after a selected numeric attribute increases by an amount beyond a threshold, using the following criteria:

  – Quantity of tuple
  – Age of tuples
  – Punctuation marks (special tuple separators understood by Streams)

- The window trigger policy

  The window trigger policy defines when the operator associated with the window performs its function on the incoming data. For example, a trigger policy can be based on a period of time or a number of tuples.

- The effect of adding the "partitioned" keyword on the window

  For supported operators, the use of the optional partitioned keyword will cause multiple window instances to be created for the stream in question. The number of instances will depend on the number of distinct values for the selected attributes, meaning the runtime values of the attributes used to define the group. This is depicted in the use of the partitioned keyword.

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As the application runs and new combinations of attribute key values are received, additional window instances are created dynamically. Each window instance on the stream will operate, as described above, independently of each other within the common set of characteristics, as shown in Figure 5-4.

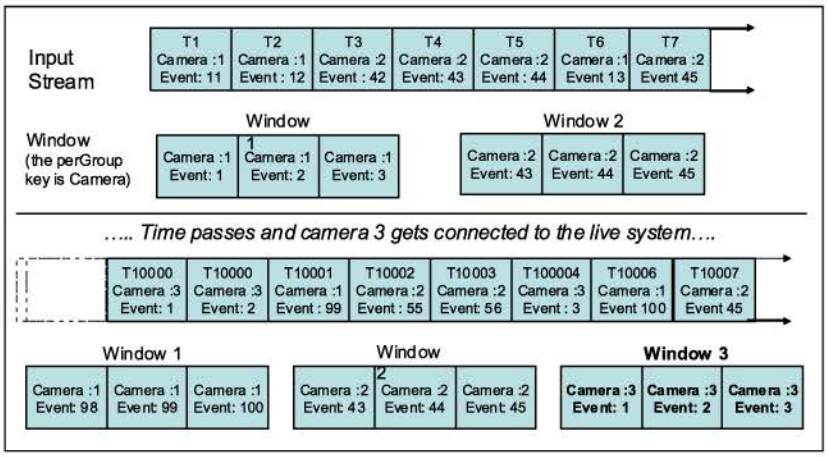


Figure 5-4 Partitioned keyword

Referring to Figure 5-4, InfoSphere Streams is being used as part of a security monitoring solution. The system has motion-sensitive security cameras that send data through captured image events when a security event triggers them. Sliding windows have been defined that have an eviction policy using a counter limit of three tuples. Therefore, in this case, the latest three events will be present in each window. The partitioned keyword has been used and the "group key" is the camera ID, which means that the number of physical cameras does not need to be hard coded anywhere in the application. Rather, the application will dynamically create additional windows as cameras are added and they start sending security event data.

Language syntax for windows

For operators that support windows, and where windows are required by the developer, the language requires the definition of the window characteristics be specified under the window clause for an operator. The window definition is placed after the relevant stream name, as shown in Example 5-10.

Example 5-10 Defining a group of sliding windows

```
stream<BeatL, BeatR> Join1 = Join(BeatL; BeatR) {
   window
      BeatL : partitioned, sliding, count(20);
```


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```
      BeatR : partitioned, sliding, count(1);

   param
      match : BeatR.name == BeatL.firstName + " " + BeatL.lastName &&
department == "HR";
      partitionByLHS: BeatL.id;
      partitionByRHS: BeatR.jobCategory;

   output
      Join1 : salary = salary * 2ul;
}
```

In Example 5-10 on page 216, a left-side sliding window has been defined and will have an eviction policy of count(20). This means that when the 21st tuple arrives, the oldest tuple (in order of arrival) will be evicted. The trigger policy for Join by default is count(1), which means the operator performs its function on the set of rows in the window every time a new tuple arrives and after any evictions that its arrival might cause.

A set of such sliding windows is created on the tuples in the first input stream (BeatL) because the partitioned keyword was used. The number of windows in the set will correspond to the partitionBy parameter supplied by the developer, specifically in the operator parameters section. These parameters need to identify the set of attributes used to define a group.

In Example 5-11, we define a single tumbling window on the input port to the operator. The tumbling window triggers the operator action every 60 seconds on whatever tuples have arrived in that time. The tuples in the window are then completely discarded, thus emptying the window. The time is then reset and the cycle repeats. There is only one window associated with inputStream1 because the partitioned keyword was not used.

Example 5-11 Defining a single tumbling window

```
type
   someSchema = tuple<…>;

graph
   …
   …
   stream <someSchema> myStream = myOperator(inputStream1) {
      param
          window
             inputStream1: tumbling, time(60);
```


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```
    ...
    ...
}
```

For tumbling windows, the eviction policy is explicitly specified (with or without the partitioned keyword). The options are the following:

- <punct()>: Punctuation-based tumbling windows
- <count()>: Number of tuples-based tumbling windows
- <time(seconds)>: Time-based tumbling windows
- <delta(attribute-delta)>: Change in a non-decreasing numeric amount

The eviction policy needs to be explicitly defined for tumbling windows. There is no explicit trigger policy definition in the tumbling windows because the eviction policy always matches the trigger policy. When the tumbling window becomes full, it triggers/performs the action intended by that SPL operator and then evicts all stored tuples in the window.

For sliding windows, both the eviction and trigger policy must be specified and they must be specified in that order (again, with or without the partitioned keyword). There are three choices for each policy:

- <count()>: The number of tuples-based sliding windows
- <time(seconds)>: The time-based sliding windows
- <delta(attribute-delta)>: The change in a non-decreasing numeric amount

Excluding partitioned, this results in a choice of nine possibilities of sliding window definition, specified below in <evictionPolicy,triggerPolicy> order:

1. <count(n),count(n)>
2. <count(n),time(seconds)>
3. <count(n), delta(attribute,value)>
4. <time(seconds),count(n)>
5. <time(seconds),time(seconds)>
6. <time(seconds,delta(attribute,value)>
7. <delta(attribute,value),count(n)>
8. <delta(attribute,value),time(seconds)>
9. <delta(attribute,value),delta(attribute,value)>

Sliding windows do not support a trigger or eviction policy based on punctuation.

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In Example 5-12, we illustrate a sliding window using an attribute-based eviction policy and a time-based trigger policy. In this example, temperature data is collected from national weather monitoring stations. Each weather observation has a weather observation time. The observations are guaranteed to arrive in order of observation by time and observations arrive approximately every minute from each station. However, it is not guaranteed that observations will not be missed or that the number of seconds past the top of the minute will be the same for each station.

Example 5-12 Sliding window with an attribute-based eviction policy

```
// calculate a 6-hour, running average based on temperature
observations
type
   temparatureStream = tuple<rstring monitoringStation, float32
temperature, int32 observationTime>;
   expression <uint32> $UINT32_SECONDS_IN_6_HOURS : 21600;

graph
   ...
   stream <rstring monitoringStation, float32 dailyAverageTemp>
dailyAverageTemps =
      Aggregate(temparatureInputStream) {
      window
         temperatureInputStream: partitioned, sliding,
            delta(observationTime, $UINT32_SECONDS_IN_6_HOURS),
time(90);

      param
         partitionBy: monitoringStation;

      output
         dailyAverageTemps: monitoringStation = monitoringStation,
Average(temperature);
   }
```

In Example 5-12, we have made use of the following constant definition:

```
$UINT32_SECONDS_IN_6_HOURS : 21600
```

This definition allows us to use the given meaningful name instead of just the integer constant anywhere in the code that follows this definition, primarily to make the code more readable. This and other features of the type clause are described in more detail in the SPL language specification file.

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Note that the sliding window uses an attribute-based eviction policy and a time-based trigger policy.

The time-based policy is specified here as time(90), meaning the aggregator outputs a tuple containing the running average every 90 seconds.

The following line is where the attribute-based eviction policy is used:

```
delta(observationTime, $UINT32_SECONDS_IN_6_HOURS)
```

The attribute observationTime contains a number representing the time stamp of the observation. The value is equal to the number of seconds since January 1,1970.

The selected eviction policy states that a tuple will be evicted from the window when a new tuple arrives that has an observation time that is greater than six hours newer than the tuple being considered for eviction.

The aggregator specifies the partitioned grouping attribute in the monitoringStation code lines by using the syntax partitionBy and then calculates the average using the Average () aggregate function.

5.1.6 Stream bundles

It is important to note that the stream bundle feature was supported in earlier versions of InfoSphere Streams, that is, Version 1.2.1. This feature is no longer available in the SPL language as of Streams V2.0. Even though the stream bundle construct is not available in SPL, the same function can be easily emulated by attaching multiple streams to the same port in the current version of SPL.

5.2 Streams Processing Language operators

In this section, we describe the main features of the Streams Processing Language operators, including code samples for each one.

This section is not intended to be a substitute for the language reference manuals included with the product software, but is intended as a guide for you to more readily understand the examples shown in this chapter.

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Which operator(s) are needed

There are 29 SPL standard toolkit operators that are grouped in three categories, as shown in the following list:

- Relational operators
- Adapter operators
- Utility operators

All the operators listed below offer a range of powerful functions:

- Filter: Selectively removes tuples from a stream
- Functor: Filters, transforms, and performs functions on the data
- Punctor: Transforms input tuples into output tuples and adds window punctuation items to the output
- Sort: Sorts Streams data on defined keys
- Join: Joins Streams data on defined keys
- Aggregate: Aggregates Streams data on defined keys
- FileSource: Reads data from a file and produces tuples as a result
- FileSink: Writes tuples to a file
- DirectoryScan: Watches a directory, and generates file names on the output
- TCPSource: Reads data from a TCP socket and creates tuples out of it
- TCPSink: Writes data to a TCP socket in the form of tuples
- UDPSource: Reads data from a UDP socket and creates tuples out of it
- UDPSink: Writes data to a UDP socket in the form of tuples
- Export: Sends a stream from the current application making it available for other applications
- Import: Receives tuples from streams made available from other Streams applications
- MetricsSink: Creates custom operator metrics and updates them with values
- Custom: A special operator that allows user-defined logic from where tuples can be submitted
- Beacon: A utility source that generates tuples when needed
- Throttle: Used to pace a stream to make it flow at a specified rate
- Delay: Used to delay a stream by a given amount
- Barrier: Used to synchronize tuples from two or more streams
- Pair: Used to pair two or more streams

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- Split: Used to split a stream into one or more output streams, based on a user-specified split condition
- DeDuplicate: Suppresses duplicate tuples that are seen within a given time period
- Union: Combines tuples from streams connected to different input ports
- ThreadedSplit: Splits tuples across multiple output ports to improve concurrency
- DynamicFilter: Decides at run time which input tuples will be passed through
- Gate: Controls the rate at which tuples are passed through by using an acknowledgement scheme from a downstream operator
- JavaOp: Calls out to operators implemented in Java

Table 5-1 is provided as a guide in selecting which operator(s) to use for a given type of task.

Table 5-1 A guide to use of the operators

Task	Operator(s) to use	Notes
Read or write external sources and target data.	xxxxSource to read, xxxxSink to write.	The source and sink can connect to TCP or UDP sockets or read and write files.
Aggregate data.	Aggregate.	Window enabled operator.
Join or lookup.	Join.	Window enabled operator.
Pivot groups of data into lists.	Aggregate.	Window enabled.
Derive new or existing attributes.	Functor.	The functor can retain values between tuples, use state variables, and access prior tuple data (history).
Filter data out.	Filter, Functor.	
Drop attributes.	Functor.	
Split data with different characteristics into separate streams.	Split.	

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Task	Operator(s) to use	Notes
Run multiple instances of an operator on different sets or partitions of data in the same stream for performance gains.	Precede that operator with a split and have several copies of the your required operator in the job. Split the input stream on the data characteristics by which you want to partition.	
Collect data streams together.	If the streams have the same column attributes, any input to an operator can perform this task through using a semicolon separated list. If you need to coordinate the timing of data collection, use a barrier or Delay operators.	
Coordinate the timing of data in different streams.	Evaluate the use of windows, the delay, and the Barrier operators corresponding to the distribution, synchronization, and downstream processing requirements.	
Sort data to meet downstream required dependencies.	Sort.	Sort is a window enabled operator.
Drop one or more columns.	All operators can perform this task; just do not define a matching output attribute for the input attribute to be dropped.	
Poll a directory for new files to appear (when copied by external applications).	DirectoryScan.	
Provide application-specific custom metrics that can be externally viewed using the streamtool and the Streams Live Graph tool.	MetricsSink.	

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Task	Operator(s) to use	Notes
Add custom logic in your SPL program with an added option to maintain state.	Custom.	
Generate random test tuples with some amount of customization to the generated attribute values.	Beacon.	
Control the rate at which tuples flow in the application.	Throttle.	
Delay a stream by a user-specified amount.	Delay.	
Pair tuples from two or more streams.	Pair.	
Eliminate duplicate tuples during a specified time period. (Commonly needed in telco applications.)	DeDuplicate.	
Combine tuples from streams arriving at different input ports.	Union.	
Fan out the incoming tuples in a way such that the tuples emitted on different output ports are processed concurrently.	ThreadedSplit.	
Control or filter which tuples will be passed through at run time.	DynamicFilter.	
Build a load balancer to control the rate at which a downstream operator can consume tuples.	Gate.	
Call out to pre-existing Java class implementations.	JavaOp.	

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5.2.1 Operator usage language syntax

In Figure 5-5, each input port can receive tuples from multiple streams, providing that when this is done, each of those streams has the same schema. However, each separate input and output port can have different schemas as required.

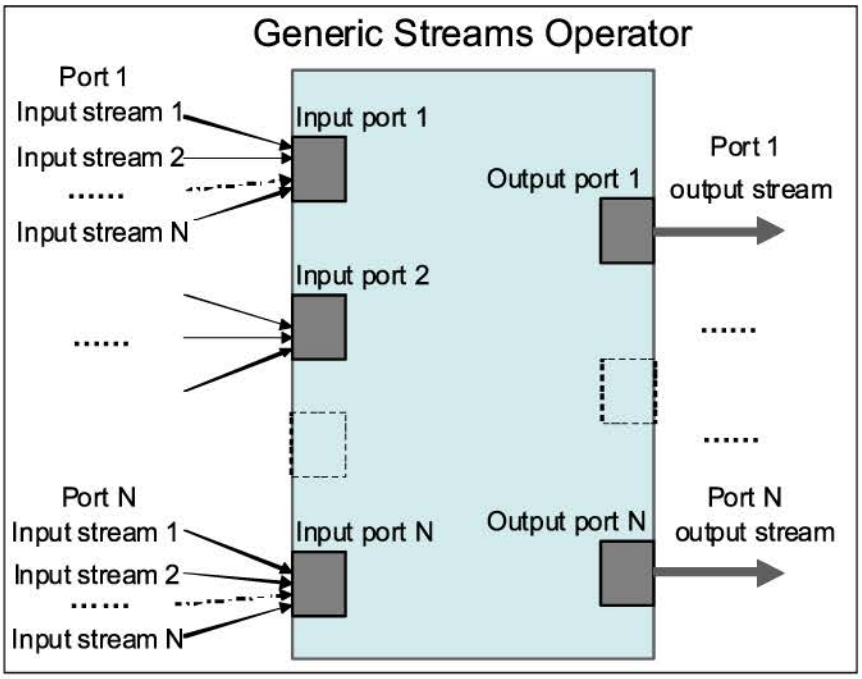


Figure 5-5 Operator inputs / outputs

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The language syntax for all operators follows the structure shown in Example 5-13.

Example 5-13 Operator language syntax

```
(stream <outputStream1Schema> outputStream1name; stream
<outputStream2Schema> outputStream2name; …; stream
<outputStreamNSchema> outputStreamsNname) =
   operatorName(inputPort1Streams1, inputPort1Stream2,
inputPort1StreamM; …; …;
   inputPortNStream1, inputPortNStream2, …, inputPortNStreamM) {
   param // Operator parameters are specified below
      …

   output // Output stream attribute assignments are done below
      …,
}
```

Note that the example shows the general case of an operator having several input and output streams.

We have also shown several input streams going to the same input port on that operator. Be aware that when this is done, the streams on the same port must have the same schema.

Not all built-in operators support multiple input ports or multiple output ports. The minimum is one input port or one output port, as in the case of a source or sink.

When operators support more than one input or output port, in many cases the number of ports used for input or for output for any given operator instance is determined at compile time, corresponding to the required application.

The use of each operator must include both types of parenthesis, (), and {}. The contents of the param clause may contain optional operator parameters and the output clause may optionally contain derivations of the outputSteams attributes. If the derivation for an output attribute is not explicitly listed, the attribute derivation is "auto matched" to a corresponding input-named attribute.

A detailed description of the use of each of the operators is provided in the following sections.

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5.2.2 The Source operator

Source operators may be used to read external data into a Streams application from files and TCP/IP and UDP sockets. The file or socket is specified using a uniform resource identifier (URI). In SPL, there are separate Source operators for dealing with files and sockets.

Using the FileSource operator to read tuples from a file

An example of how to use the FileSource operator to read from a file is shown in Example 5-14.

Example 5-14 Using the Source operator to read from a file

```
stream <int32 callerNumber, rstring name> myStream = FileSource() {
   param
      file: "myFile.csv";
      format: csv;
      hasDelayField: false;
}
```

Where:

- The file parameter is used to specify the file name from where the tuples will be read.
- The schema of the output stream is int32, rstring, that is, the output tuples will have two attributes each.
- The file name specified above does not include a full path. In this case, the Streams program expects to find the file in a data directory beneath the directory of the `.spl` file containing the code, so in this example the relative file path would be `./data/myFile.csv`.
- The hasDelayField parameter is specified so that the Source operator does not expect a delay duration attribute in the input stream.
- The format parameter indicates that the developer expects the data for each tuple to be on a separate line with each attribute comma separated in order of the schema definition.

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- Omitting the format parameter would cause the operator to expect each incoming attribute to be denoted in comma separated name:value pairs with each tuple new line delimited, as shown in Example 5-15, with an ASCII file containing two attributes per tuple in the default format.

Example 5-15 Example ASCII file

```
445558444123,Priti
15553120213,Davis
555551239871, Lee
```

Attributes that are one of the supported list types are represented using square braces [ ]. For example, [1,2,3] could be used for an list<int32>.

Boolean, true or false, attribute values are represented in a file by the characters T and F, respectively.

Using the TCPSource operator to read from a socket

The TCPSource operator can read a stream of data from a TCP/IP socket as well as from a network socket, as shown in Example 5-16. In this case, the corresponding data source may be a client or a server source. The use of an external service by reference to a name, rather than the traditional hostname:portname, may also be used. However, this setup requires a available name lookup server in the network that can perform the translation of a service name to a hostname:portname. Because it is a source, TCPSource does not have any input ports.

Example 5-16 Reading from a TCP/IP socket

```
stream <…> mySourceStream = TCPSource() {
   param
      role: client;
      address: "myexternalhost.ibm.com";
      port: 4512;
 }
```

In Example 5-16, the TCPSource operator is being asked to connect to the host adapter with network address myexternalhost.ibm.com. The connection will attempt to be made over port 4512.

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There is another operator to connect to UDP data sources and it is called UDPSource. In Table 5-2, we summarize important parameters for TCPSource and UDPSource operators.

Table 5-2 Supported protocol specifiers

Parameter	Description
role	A mandatory parameter that specifies whether the operator is server-based or client-based. It can either be server or client.
address	A destination server address if the role is specified as client.
port	Depending on the role, it specifies either the port where the connections will be accepted or the destination server port.
name	A developer can decide to use a descriptive name that will be automatically register the name:port pair with the name service available within the Streams run time. Other operators in the application use the name:port to communicate with this Source operator.
receiveBufferSize	An optional parameter that can be used to override the default kernel receive buffer size.
format	It specifies the format of the incoming tuples (csv, line, txt, and so on).

The above listing is only a sample. There are more operator parameters available within the SPL documentation.

The Source operator and tuple inter-arrival timing

The Source operator might expect an additional, first attribute to the output stream, which is the inter-arrival delay measured in seconds between the tuples. This inter-arrival delay is frequently not required. Where timing is important, the tuples may contain a time stamp attribute. If inter-arrival delays are not present in the incoming data tuples, the hasDelayField parameter should be set to false in the operator parameters section.

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The Source operator and initialization timing delay

For testing purposes, where sample input data is collected from a file rather than from a continuous input stream, it is often required that the Streams application flow, as a whole, is fully initialized prior to the Source operator sending the first tuple. This action avoids the possibility of the first few tuples being processed and discarded. In this case, the optional initDelay=<value> parameter can be added to the Source operator parameters section. The term <value> is a numeric constant representing the number of seconds to wait before sending the first tuple.

Additional useful parameters for FileSource

FileSource can optionally have one input port when it is used in combination with the DirectoryScan operator. In that case, the DirectoryScan operator will send a file name in its output tuple, which will be fed into the FileSource input port. The FileSource operator can take any of the following operator parameters (which will be helpful in many real-life application scenarios):

1. hotFile: A Boolean type used to indicate if the input file will keep growing.
2. deleteFile: A Boolean type that specifies whether the file should be removed after processing is completed for that file. This parameter cannot be specified if hotFile is specified.
3. moveFileToDirectory: An rstring type used to specify that the file should be moved to a directory after processing is completed for that file. This parameter cannot be specified if hotFile or deleteFile is specified.

The three variations of Source operator that introduce punctuation shows the usage of these parameters, and are shown in Example 5-17.

Example 5-17 The three variations of Source operator

```
type
   cityData = tuple<rstring city, rstring country, uint32 population,
uint32 medianAge, uint32 percentageEducated>;

graph
   stream <cityData> CityDataRecord1 = FileSource() {
      param
         file: "../test1/Population.txt";
         hotFile: true;
   }

   stream <cityData> CityDataRecord2 = FileSource() {
      param
         file: "../test2/Population.txt";
         deleteFile: true;
```


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```
   }

   stream <cityData> CityDataRecord3 = FileSource() {
      param
         file: "../test3/Population.txt";
moveFileToDirectory: "/tmp/Processed-Files/";
   }
```

5.2.3 The Sink operator

The Sink operator is used to perform the reverse function of the Source operator. It receives an input stream and externalizes the tuples to the desired output format, which may be a continuing transmission to a TCP/IP socket or writing the tuple data to a csv-formatted file on the Linux file system.

Accordingly, the Sink operator has one input port and no output ports.

Sink operators also come in three types:

- FileSink is used to write tuples into a file.
- TCPSink is used to send tuples targeted to a TCP address.
- UDPSink is used to send tuples targeted to an UDP address.

Because there is no output port for Sink operators, a typical Sink SPL statement may appear as in the following example:

```
() as FileWriter1 = FileSink(CityDataRecord3) {
      param
         file: "../test3/Population-Output.txt";
         hasDelayField: false;
   }
```

Note the use of the parentheses, "()" on row one in positions 1 and 2 to indicate that there is no output stream emitted by a Sink operator.

Punctuation and the Sink operator

By default, the Sink operator does not write punctuation markers to text-based output. For example, they are marked by the # character. To disable this behavior, use the writePunctuations parameter and set it to true.

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5.2.4 The Functor operator

The Functor operator is used where the developer needs to perform functional transformations, including filtering and dropping attributes from the input stream.

The Functor has one input port and one or more output ports. It processes the input on a tuple by tuple basis, so window functionality is not required or supported.

A Functor operator is declared as shown in Example 5-18.

Example 5-18 Declaring a Functor operator

```
(stream <rstring accountHolder, rstring accountNumber> FirstOutput;
 stream <rstring accountHolder, rstring ticker> SecondOutput;
 stream <rstring accountHolder, int32 quantity> ThirdOutput) =
Functor(AccountRecord) {
    param
       filter: quantity < 8000;
 }
```

A Functor operator takes an optional filter parameter, which specifies the condition that determines which input tuples are to be operated on. It takes a single expression of type Boolean as its value. If the input tuple is not filtered, any incoming tuple results in a tuple on each of its output port.

In Example 5-19, we show code that calculates a running total that is output after every tuple and reset after a change of value of the key attribute. This action is done by using the state-keeping facility available within an operator.

Example 5-19 Using Functor logic to derive a new output attribute

```
type
   mySchema = tuple<int32 key, int32 value>;

graph
   stream <mySchema, tuple<int32 total>> myStreamWithTotal =
Functor(myInputStream) {
      logic
         static: mutable int32 _total = 0, int32 _lastKey = -1;

      param
         filter: true;

      onTuple myInputStream: {
         if (_lastKey != key) {
```


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```
            _total = data;
            _lastKey = key;
         } else {
            _total += data;
         } // End of if (_lastKey != key)
      } // End of onTuple myInputStream

      output myStreamWithTotal: {
         key = key;
         data = data;
         total = _total;
      } // End of output myStreamWithTotal
   } // End of Functor.
```

Functors can also easily access previous input tuples, which is referred to as *history access*. For example, to achieve access to the previous tenth tuple attribute, called temperature on input port named MyInput, you can use the expression MyInput[10].temperature.

Knowing this, Example 5-19 on page 232 can be simplified, eliminating the need for the lastkey variable. The custom logic section could now read as follows:

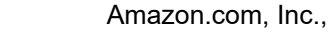
```
if (key != myInputStream[1].key) {
        _total = data
     } else {
        _total += data
     }
```

Where the myInputStream[1].key refers to the value of the previous tuple key attribute.

Note the following points regarding Functor history processing:

- The language currently supports a literal number in the code (known at compile time) that defines the number of tuples to go back. Using a variable as an index here is not supported. The number "to go back" has no limit, but be aware that the compiler may allocate additional buffering space to achieve larger index number processing.
- If your code refers to tuple numbers, specifically ones prior to the first tuple, you should be aware of what happens prior to data being received by the program. In this case, the attributes will have default values. Those are 0 for numerics, the empty string for strings, false for Boolean variables, and the empty list for lists.

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Punctuation and the Functor operator

The Functor operator preserves any punctuation it receives. Therefore, punctuation passes through the Functor operator unchanged, in order, on receipt and irrelevant of any Functor processing or filtering.

If it is required to insert punctuation based on tuple attribute input condition(s), the Punctor operator should be used.

5.2.5 The Aggregate operator

The Aggregate operator is able to perform summarization of user-defined groups of data where the summarization is based on data of all values. Also, processing may be divided into groups where one or more attributes have the same values. This operator has one input port, one output port, and supports both sliding and tumbling windows. In Table 5-3, we show the choice of functions on a group of tuples:

Table 5-3 Aggregator functions

Function	Description
Count()	Count the tuples in the group.
Min()	Determine the minimum value of an attribute.
Max()	Determine the maximum value of an attribute.
Average()	Determine the average of an attribute.
Sum()	Accumulate the total of an attribute.
First()	The first value of an attribute.
Last()	The last value of an attribute.
CountDistinct()	The count of distinct values of the attribute.
Collect()	Create a Streams List data type containing all the values of an attribute.
CollectDistinct()	As Collect(), except the list contains only distinct values.
CountAll()	Total number of tuples in windows of all groups.
CountGroups()	Number of groups.
CountByGroup()	Create a Streams List data type containing the group sizes for all groups.

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In Example 5-20, we show an example use of the Aggregate operator.

Example 5-20 Aggregate operator usage

```
// Assumed aggregator input stream schema
type
   stockPrices = tuple<rstring stockSymbol, float32 price>;
   avgStockPrices = tuple<rstring stockSymbol, float32 avgPrice>;

graph
   …
   stream <avgStockPrices> avgStockPrice = Aggregate(inputStockStream)
{
      window
          inputStockStream: partitioned, sliding, count(30), count(1);
          partitionBy: stockSymbol;

      output
         avgStockPrice: stockSymbol = stockSymbol, avgPrice =
Average(price);
   }
```

In regards to Example 5-20:

- We are using a sliding window along with the partitioned keyword. The window has an eviction policy that is "count-based" at 30 tuples and the trigger policy is also count-based for each tuple. The attribute being used for the group key is stockSymbol.
- We are using the Aggregate operator Average() function, which calculates averages, which means that we are calculating the moving average for each stock symbol. The example will output a calculation of the average of the last 30 tuples received for each stock symbol. Such a calculation might be used in company-based, stock-trend analysis.

Punctuation and the Aggregate operator

The prior text has noted that the Aggregate operator may use punctuation as a method to activate the trigger and eviction policy actions for tumbling windows (but not sliding windows).

The Aggregate operator inserts a window marking punctuation into the output stream after the aggregation operation is completed and a batch of tuples are emitted.

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5.2.6 The Split operator

The Split operator has one input port and may have one or more output ports. It may be used to split an input stream into various output streams. Parameters specified within the Split operator are used to decide which input tuples are dispatched to which output tuples. This type of operator will typically route a tuple based on specific attribute characteristics.

The Split operator does not (need to) support windows because it functions on each input tuple one at a time, routing it to the required output port(s).

The input and output stream schemas must be the same for the Split operator.

The Split operator is declared as shown in the following example:

```
(stream <OutputStreamSchema> OutputStream1;
 stream <OutputStreamSchema> OutputStream2;
 …
stream <OutputStreamSchema> OutputStreamN) = Split(InputStream1, …,
InputStreamN) {
   param
      index: hashCode(name);
}
```

There are three mutually exclusive forms of splitParameters:

- An expression returning an uint64
- An expression returning an list<uint64>
- A key-mapping file

These forms are described in more detail in the following text. In each of the descriptions, it is assumed that the Split operator has N output ports numbered consecutively 1 through N. The expressions that make up the Split operator parameters typically call for runtime comparisons with values of specific tuple attributes.

- An expression returning an Integer

  In this form, a tuple can either be dropped or sent to exactly one output port. If the integer expression evaluates to -1, the input tuple is discarded. If the expression evaluates to 0, the tuple is dispatched to output port 0 (the first port). If the expression evaluates to 1, the tuple is dispatched to output port 1, and so on. In general, a non-negative expression value of e means the tuple should be dispatched to output port (e mod *N*), where N is the number of output ports.

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Example 5-21 shows use of the Split operator with a integer expression.

Example 5-21 Split operator with an integer expression split parameter

```
type
   businessAccounts = tuple<rstring accounted, float64
averageBalance>;

graph
   …
   (stream <businessAccounts> highValueAccounts;
    stream <businessAccounts> mediumValueAccounts;
    stream <businessAccounts> lowValueAccounts) =
Split(inputStreamOfAllAccounts) {
       param
          index: (averageBalance >= 10000.00 ? 0 : (averageBalance
>= 5000.00 ? 1 : 2));
    }
```

High value business accounts are classified with average balances great than or equal to 10000, medium value accounts are great than or equal to 5000 and less than 10000, and low value accounts have average balances below 5000.

Note we use the conditional expression. The format is as follows:

```
if (averageBalance >= 10000.00) then send the tuple to port 0.
if (averageBalance >= 5000.00 and averageBalance < 10000.00) then
send the tuple to port 1.
if (averageBalance < 5000.00) then send the tuple to port 2.
```

Note that in the example we nest the ternary conditional operators to achieve the required result.

- An expression returning an IntegerList

  In this case, the tuple can be dropped or sent to one or more output ports simultaneously. In this form of split parameter, a list of integers is provided using a streams list<uint64> type. Each integer in the list is then interpreted by the operator in the same way as the integer expression case previously shown. The benefit of this option over the Integer operator is that a tuple can be sent to several output ports simultaneously.

  Example 5-22 shows a split using an IntegerList.

Example 5-22 A split using an IntegerList

```
// in this example we split book authors into streams of the types
of #genre of books they have written
// authors often write books of more than one genre..
```


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```
// schema of allAuthors stream:
type
   authorGenres = tuple<rstrng authorId, list<uint64>
genresWritten>;

graph
   …
   (stream <authorGenres> SciFi;
    stream <authorGenres> Horror;
    stream <authorGenres> Crime;
    stream <authorGenres> Romance;
    stream <authorGenres> Fantasy) = Split(AllAuthors) {
      param
         index: genresWritten;
}
```

In Example 5-22 on page 237, the input stream allAuthors contains tuples that contain author identifiers and a list of the genre(s) of book(s) they have written.

For example, if an input tuple genresWritten attribute contained the values [0,4], this would be used to indicate that the associated author has written books of both SciFi and Fantasy genres. So this input tuple would be dispatched to two of the five output streams.

- A key-mapping file

  In this form, the operator parameters contains a URI file and an attribute on which to perform the split. The URI file points to the key-mapping file.

  The key-mapping file is a csv-formatted file. Each line contains a record of the following format:

  `<atrribute-value>, <comma seperated list of ports>`

  If the input tuple attribute value matches the first value on any of the lines, the tuple is dispatched to the list of output ports given on the remainder of the line.

  The benefit over the previous example is that the key-mapping file is an external configuration data file that could be changed or updated without requiring a code change.

  Example 5-23 provides an example using a key-mapping file.

Example 5-23 Split operator using a key-mapping file

```
// this is the same example as in A split using an IntegerList, that
has been re-written #to use a key-mapping file
```


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```
// so the list<uint64> is now not part of
// the input or output stream schema..
// in this example we split book authors into streams of the types
of #genre of books they have written
// authors often write books of more than one genre..

// schema of allAuthors stream:
// schema of allAuthors stream:
type
   authorGenres = tuple<int32 authorId>;

graph
   ...
   (stream <authorGenres> SciFi;
    stream <authorGenres> Horror;
    stream <authorGenres> Crime;
    stream <authorGenres> Romance;
    stream <authorGenres> Fantasy) = Split(AllAuthors) {
       param
          file: "MyMapping.txt";
          key: authorId;
}

// the contents of the MyMapping.txt might contain
default, -1
1,0,3,4
2,3
3,1,2

// this would mean
// author 1 has written SciFi, Romance and Fantasy
// author 2 has written Romance
// author 3 has written Horror and Crime
```

Punctuation and the Split operator

Similar to the Functor operator, the Split operator passes punctuation through unchanged. If the split has multiple output ports, an incoming punctuation is passed to all output ports unchanged. The Split operator itself does not use punctuation to determine split functionality

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5.2.7 The Punctor operator

The Punctor operator has one input port and one output port. Window grouping functions are not supported or required because the operator works on a single tuple at a time.

The primary use of the Punctor operator allows the solution designer to insert punctuation marks into a stream based on required conditions. Typically, this action is done in preparation for downstream operator behavior when it is required for a tumbling window trigger and eviction policy to be based on punctuation.

The operator parameters sections support a Boolean expression, which when evaluated to true, will cause a punctuation mark to be inserted in the output stream. The expression may refer to prior tuples using the syntax for history processing described for the Functor operator. A before or after positional keyword is also included to determine if the punctuation is inserted before or after the tuple causing the expression to evaluate to true respectively.

The output attribute assignment section of the operator definition may include attribute derivation expressions as per the Functor operator.

In Example 5-24, we demonstrate the use of the Punctor operator.

Example 5-24 Using the Punctor operator

```
// in this example we insert punctuation on a key change in
// the data stream. The punctuation marker is inserted at the end of
each series of a particular key value before the next series of tuples
having the key attribute with a different value.

type
   exampleSchema = tuple<int32 key, rstring data>;

graph
   ...
   stream <exampleSchema> punctuatedStream = Punctor(someInputStream) {
       param
          punctuate: key != someInputStream[1].key;
          position: before;
   }
```


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5.2.8 The Delay operator

The Delay operator has one input port and one output port. Its function is to delay a stream by a number of seconds specified by a float64 parameter. It does not use windows because it operates on a tuple-by-tuple basis. A Delay operator is typically used when it is required to more closely synchronize tuples from different streams and where relative timing is important to downstream operator processing. In Example 5-25, we demonstrate the use of the Delay operator.

Example 5-25 Using the Delay operator

```
// delay a stream by 1.2 seconds
stream <someSchema> delayedStream = Delay(inputStream) {
   param
      delay: 1.2;
}
```

Punctuation and the Delay operator

The Delay operator passes through any punctuation marks in the stream unchanged after the specified delay while maintaining the relative position of the punctuation marker against the surrounding tuples.

5.2.9 The Barrier operator

The Barrier operator is used to combine (or merge) multiple input streams to one output stream where the input streams are logically related. It has two or more input ports and one output port. An output tuple is emitted only when an input tuple has been received by each and every input port. The output tuple attributes can be explicitly derived in the output attributes section of the operator definition from some or all of the input tuples set of attributes.

The Barrier operator does not require or support windows because it operates on a tuple-by-tuple basis for each input stream.

A typical usage is where a stream has earlier been split into two or more streams because performance can be gained by processing each of the two streams together before subsequently recombining them using the Barrier operator. In this scenario, it may be important that the order and number of tuples in the prior split stream is maintained. In other scenarios of merging or combining streams, the Join operator may be more appropriate.

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The Barrier operator does not require any parameters in the parameters section. We show a demonstration of the use of the Barrier operator in Example 5-26.

Example 5-26 Using the Barrier operator

```
type
   // schemas of the input streams to the barrier
   stream1Schema = tuple<int32 i, rstring a>;
   stream2Schema = tuple<int32 i, rstring b>;
   stream3Schema = tuple<int32 i, rstring c>;

   // schema of the output stream from the barrier
   outputSchema = tuple<int32 i, rstring x, rstring z>;

graph
   …
   stream <outputSchema> outputStream = Barrier (stream1; stream2;
stream3) {
      output
         outputStream: i = stream1.i, x = a, z = c;
   }


// note that where input streams contain identicailly named
// attributes e.g 'i' in the above example we explicity refer the
// the input stream number to derive the output attribute from to
// eliminate any ambiguity as to which input stream attribute of that
// name we are referring to.
```

Punctuation and the Barrier operator

The Barrier operator does not propagate punctuation. The rationale for this is that although incoming streams may have punctuation, the resulting output stream is an interleaved combination of the input tuples and therefore it would not be possible to relate punctuation to the relevant stream.

5.2.10 The Join operator

The Join operator is used to perform a relational join of two input streams. A relational join may be inner, left, right, or full outer join. The join condition and the type of join are specified in the operator parameters section.

In the description of the join functionality that follows, it is essential that you are familiar with the description of window characteristics provided earlier in 5.1.5, "Streams windows" on page 212.

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The Join operator has two input ports and one output port. It supports sliding windows but not the tumbling windows for both its input ports.

The eviction policy for a join may be count, time, or attribute-delta-based in common with normal sliding window characteristics.

The trigger policy for a join is always count(1). A count(1) trigger policy means that the join processing always occurs as each input tuple arrives on either input port. Because the trigger policy for each input port window is always count(1), Streams does not require it to be explicitly stated in the code of the operator definition. Note that this may make the window definition, in the code for the join, initially appear to you to look like a tumbling window definition. However, do not be deceived; recall that the join only supports sliding windows.

The operation of the join is as follows: As each new tuple is received on either port, the new tuple is matched against all of the tuples that are in the opposite port window. For each set of tuples that satisfies the join condition, an output tuple is constructed using the rules defined in the operator attribute derivation section of the code.

The partitioned keyword may also optionally be used where required on either or both input streams. Note, in this case, that the time-based eviction policy is not supported with the partitioned keyword for the join. The choices are confined to either count-based or attribute-delta-based eviction. In this case, a number of windows are created on the relevant input streams and then grouped on the relevant distinct runtime values of the attribute keys specified in the join criteria.

In Example 5-27, we demonstrate a left outer join.

Example 5-27 Streams application performing a left outer join

```
namespace my.sample;

composite Joins {
   graph
      stream <int32 key, rstring decode> decode = FileSource() {
         param
            file: "decode.dat";
            hasDelayField: false;
            format: csv;
      }

      stream <int32 key, rstring someData> primary = FileSource() {
         param
            file: "primary.dat";
            hasDelayField: false;
```


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```
            format: csv;
      }

      stream <int32 key, rstring decode, rstring someData> joined =
Join(primary; decode) {
         window
            primary: sliding, count(0);
            decode: partitioned, sliding, count(1);

         param
            match: primary.key = decode.key;
            algorithm: leftouter;
            partitionByRHS: primary.key;

         output
            joined: key = primary.key, decode.decode, primary.someData;
      }

      () as FileSink1 = FileSink(joined) {
         param
            file: "decode-output.dat";
      }
}
```

This example joins two csv-formatted input files on the integer key attribute. The decode file is assumed to contain a text description associated with numeric key identifiers. A left outer join is used in case there is a key value that cannot be decoded. In that case, the key is still output to the output file with a value of the empty string for decode.

The primary stream contains a list of keys to be decoded. Note that it flows into the first or left input port to the Join operator. A <count(0)> eviction policy for this is used, meaning that the input tuple is immediately discarded after processing.

The decode stream uses a <count(1), perGroup > Window definition. This means that a number of windows are created in the stream on the second input port to the join, each with a size of one tuple. The number of windows will equate to the number of distinct values for the key in the decode file. This approach means that we hold the decode values continuously within the memory of the operator.

Assume we have the tuple data shown below for the `primary.dat` and `decode.dat` files:

```
primary.dat
1,def
```


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```
3,ghi
0,abc

decode.dat
0,alpha
1,beta
```

Then, the following output would be in the `decode-output.dat` file:

```
1,beta,def
3,,ghi
0,alpha,abc
```

The second line of output contains an empty string for the decode attribute, as there is no matching key value for 3 in `decode.dat`.

Punctuation and the Join operator

The Join operator inserts punctuation on its output stream to delineate the sets of resulting, matching tuples for each pair of windows processed.

5.2.11 The Sort operator

The Sort operator sorts a set of tuples in a window by a defined set of attribute keys. Single and multiple sort keys are supported, each of which may be specified as ascending or descending for ascending or descending sorts, respectively.

Sorts are typically used either as a requirement prior to exporting the tuples through a sink to meet an external target requirement, or for downstream operator window requirements. For example, attribute-delta-based windowing requires the tuples to be sorted on the relevant attribute.

The Sort operator has one input port and one output port and supports sliding and tumbling windows, with some restrictions.

Tumbling windows may be defined by count, time, or punctuation. After the tumbling window is full, the sort is performed on the defined attribute keys. In Example 5-28, we show a tumbling window based sort.

Example 5-28 Tumbling window based sorts

```
// schema of input and output streams
type
   streamSchema = tuple<int32 key1, int32 key2, rstring someData>;

graph
```


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```
...
stream <streamSchema> sortedStream = Sort(inputStream) {
   window
      inputStream: tumbling, time(60);

   param
      sortBy: key1, key2;
      order: ascending;
}
```

Note that in this example the operator only ever processes the window when a tuple is received. So, if a tuple is not received in 60 seconds, the window will not be processed. The next tuple to be received after 60 seconds will trigger the sort and ejection of tuples. A consequence is that if we stop receiving tuples, the last tuples in the Sort operator will never be output.

Sliding windows may be defined only by a count-based eviction policy. Other eviction policies are not supported for sliding window based sorts.

The trigger policy for sorting sliding windows is always count(1) and it need not be explicitly specified. This situation is often called a progressive sort.

In Example 5-29, we demonstrate the use of a sliding window with a Sort operator.

Example 5-29 Sliding window based sort

```
type
   streamSchema = tuple<int32 key1, int32 key2, rstring someData>;

graph
   ...
   stream <streamSchema> sortedSchema = Sort(inputStream) {
      window
         inputStream: sliding, count(100);

      param
         sortBy: key1, key2;
         order: descending, descending;
   }
```

In this example, 100 tuples are read into the window. Then as each new tuple is read, it is placed in order in the window. Because the window is larger than the eviction policy size, the tuple in the window with the highest values of key1, key2 is output.

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Punctuation and the Sort operator

The Sort operator may process punctuation based tumbling windows.

Also, the Sort operator inserts a window marking punctuation into the output stream following the completion of the sort processing on the group of tuples in the window for all supported variations of windowing schemes described.

5.2.12 Additional SPL operators

In this chapter, we have described fourteen different SPL standard toolkit operators in detail. You should now have a good background for using the SPL standard toolkit operators that are available with the Streams product. There are additional SPL standard toolkit operators:

- Filter: Selectively removes tuples from a stream.
- DirectoryScan: Watches a directory, and generates file names in the output.
- MetricsSink: Creates custom operator metrics and updates them with values.
- Custom: A special operator that allows user-defined logic from where tuples can be submitted.
- Beacon: A utility source that generates tuples when needed.
- Throttle: Used to pace a stream to make it flow at a specified rate.
- Pair: Used to pair two or more streams. Similar to Barrier, but it will output the two tuples individually.
- DeDuplicate: Suppresses duplicate tuples that are seen within a given time period.
- Union: Combines tuples from streams connected to different input ports.
- ThreadedSplit: Splits tuples across multiple output ports to improve concurrency.
- DynamicFilter: Decides at run time which input tuples will be passed through.
- Gate: Controls the rate at which tuples are passed through by using an acknowledgement scheme from a downstream operator.
- JavaOp: Calls out to operators implemented in Java.

Thorough descriptions about these additional operators as well as code snippets that explain different ways to use them are available in the `SPLToolkitReference.pdf` file or within the InfoSphere Streams Information Center website, found at the following address:

`http://publib.boulder.ibm.com/infocenter/streams/v2r0/index.jsp`

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You should extend the SPL standard toolkit operator skills you have gained from reading this book by referring to the additional resources mentioned above. In addition, work through the many examples targeted for learning the SPL operators. Details about these examples can be found in the `samples/spl` subdirectory of the InfoSphere Streams installation. More hands-on SPL examples can be found at the IBM developerWorks® website at the following address:

`https://www.ibm.com/developerworks/mydeveloperworks/files/app?lang=en#/collection/ef9f8aa9-240f-4854-aae3-ef3b065791da`

By taking advantage of dozens of available SPL examples, new Streams developers can get a quick start on building Streams applications that use SPL operators.

5.3 The preprocessor

It is important to note that two preprocessors were supported in earlier versions of InfoSphere Streams (Version 1.2.1): One preprocessor with features such as “for loops” and another preprocessor for mixed-mode (Perl embedded within Streams code). In the current version of SPL, the first preprocessor has been dropped altogether. However, SPL provides constructs at the language level to perform some of the previously-supported features of the absent preprocessor. Mixed-mode PERL is fully supported by SPL.

Even though some of the features listed below are not offered through a preprocessor, in this section we describe how they can be done in SPL:

- Defining constants
- Including logic from other SPL files
- Application parameterization
- Loops
- Mixed mode processing with Perl

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In the following paragraphs, we provide descriptions and examples for each of these features:

- Defining constants

  If you are familiar with the C or C++ programming languages, this description will be familiar. In C or C++, the #define functionality enables the developer to define literal textual replacements for a given keyword. The coding convention is to define the text to be replaced in all upper case. Similarly, we can define constants using the SPL language feature rather than a preprocessor directive, as shown in Example 5-30.

Example 5-30 Using constants

```
composite Main {
   param
      expression <uint32> $SECONDS_PER_DAY : 86400u;
      expression <rstring> $MY_MESSAGE : "DAY_CHANGE_EVENT";

   type
      ...

   graph
      stream <someSchema> someOutputStream =
Functor(someInputStream) {
         logic
            state: {
               mutable rstring _message = $MY_MESSAGE;
               mutable boolean _dayChange = false;
            }
            onTuple someInputStream: {
               if ((getTimestamp()/1000000) % $SECONDS_PER_DAY) ==
0) {
                  _dayChange = true;
               } else {
                  _dayChange = false;
               }
            }

         param
            filter: _dayChange == true;

         output someOutputStream: message = _message;
      }
}
```


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The code snippet in Example 5-30 on page 249 uses the more meaningful text SECONDS_PER_DAY instead of 86400, and also defines a message to be output. The benefit is that it is easier to change the message text later on (for example, due to being referenced in several places) rather than searching through the code for all occurrences.

- Including/using logic from other SPL files

  The SPL language does not have syntax similar to #include, which is supported by the C/C++ preprocessor. However, SPL allows a developer to access/use logic residing in other SPL files.

  Typically, application logic from different SPL files can be accessed from an SPL application for the following reasons:

  - Common code that needs to be used in more than one Streams source file. The benefit is that the common, shared code can be maintained in one place.
  - More complex logic, with the benefit that such logic can be more easily developed and tested in a separate file by a test harness prior to using it as part of the full application as well as to assist readability of the overall code structure.
  - SPL metadata type definitions, with the benefit of also simplifying repeating metadata of a stream, that might be referenced in several source files.

  We demonstrate the use of Streams **`use directives`** in Example 5-31.

Example 5-31 Using Streams use directive (part 1)

```
namespace my.sample;
use com.acme.utils::MyTypes;

graph
   …
// testStream is a type defined in the MyTypes comosite and
// it is referenced in several source files
stream <testStream> outputStream = FileSource() {
   …
}
```

We demonstrate another use of the Streams **`use directive`** in Example 5-32.

Example 5-32 Using Streams use directive (part 2)

```
// streams metadata used in several applications could be defined in
an SPL files that
```


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```
// can be accessed in other Streams applications through the use
directive.
namespace com.acme.types;
type
   vOstream = tuple<uint32 customerKey, rstring customerName,
rstring customerType>;
   vInputStream = tuple<rstring name, uint32 id, float32 balance>;
   vTransactionStream = tuple<rstring accountNumber, uint32
accountType>;
   …
   …

composite Main {}
```

Once all the common types are defined in an .spl file as shown above, any of these type definitions can be used in other applications by declaring **use com.acme.types::*.**

Example 5-31 on page 250 and Example 5-32 on page 250 both show examples of storing common SPL type definitions in an SPL file.

- Application parameterization

  In SPL, applications can be externally parameterized by passing special arguments to the applications, either during compile time or during application submission time. The Streams compiler (sc) supports arguments that are passed in at compile time. These arguments can be accessed from within SPL code through the following three compile time argument access functions.

  ```
  rstring getCompileTimeValue(rstring name)
  rstring getCompileTimeValue(rstring name, rstring default)
  list <rstring> getCompileTimeListValue(rstring name)
  ```

  These functions can appear in any location within an SPL file. The first function returns the value of a named argument as a string. The second function returns the value of a named argument, or a default value in case the argument is not specified at compile time as a string. The third function expects the value to be a string with commas. The string will be split at the commas and the result is returned as a list<rstring>.

  The named arguments are specified as <name>=<value> on the **sc** compiler command line, as shown below:

  ```
  sc  -M my.sample::MyApp  hello=a,b,c   aname=bar
  ```


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SPL also supports another way to pass parameters into an application. It is done through submission-time values, which are arguments specified at the time of application launch. For distributed applications that run on the InfoSphere Streams run time, these arguments are specified when submitting a job through the **`streamtool submitjob command`** or through other means supported by the Streams tooling. For stand-alone applications, submission-time values are specified when launching the generated stand-alone application. These values can be accessed from within SPL code through the following submission-time value access functions:

```
rstring getSubmissionTimeValue(rstring name)
rstring getSubmissionTimeValue(rstring name, rstring default)
list<rstring> getSubmissionTimeListValue(rstring name)
list<rstring> getSubmissionTimeListValue(rstring name, list<rstring>
default)
```

To learn more about these two approaches to passing parameters into a Streams application, refer to the *SPL Compiler Usage Reference*, found at the following address:

`http://publib.boulder.ibm.com/infocenter/streams/v2r0/index.jsp`

- Loops

  SPL allows the use of loops inside the application logic in two ways. Any code block that has to be conditionally iterated can be put inside either for or while loops. SPL for loops use the syntax for (typeId in expression) and SPL while loops are just like in C or Java with the syntax while (expression) statement.

  SPL for loops are typically used to iterate over SPL collection types, such as list, map, set, and string. A for loop over a string or list iterates over the elements or characters in index order. In a for loop over a map, the loop variable iterates over the keys. It is important to note that the iterated-over collection becomes immutable for the duration of the loop.

  An SPL while statement evaluates the specified expression and executes the statements in the body of the while loop. There are three loop control statements, named break, continue, and return. A break statement abruptly exits a while or for loop. A continue statement abruptly jumps to the next iteration of a while or for loop. A return statement abruptly exits a function.

  If there is a need to replicate a block of SPL code multiple times during the preprocessor phase, Perl for loops can be used. An example of using a Perl for loop inside an SPL application is explained in Example 5-33 on page 254.

- Mixed mode processing with Perl

  The four previously described SPL features are suitable for many small to medium size Streams applications.

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However, for larger-scale applications, more extensive scripting support might be required. In this case, the language supports what are referred to as *mixed mode programs*. For mixed mode programs, the preprocessor executes an additional step where sections of the code, which are written as Perl code, are used to generate Streams code.

Mixed mode programs need to have the extension .splmm rather than .spl. Streams uses Perl to convert `.splmm` files into `.spl` files as a first step, then passes the `.spl` file through any subsequent preprocessor and compilation steps as normal, as previously described.

Any Perl code used in a `.splmm` file must be enclosed in one of two following delimiters:

- `<% perl-code-here %>`

  In this form, the code between the delimiters is passed straight to Perl.

- `<%= perl_print_expression %>`

  The following is a shorthand for a Perl print statement (that is, it is equivalent to it):

  ```
  <% print print_expression; %>
  ```

  Note that this shorthand, as well as saving the typing of the print keyword, also includes the trailing semicolon.

We do not describe the features of the Perl scripting language in this book, as it is covered extensively in many other, publicly available publications.

We also emphasize that this is a preprocessing step used to generate Streams code during compilation. The solution is not using the Perl code examples shown as part of the run time of the application.

We have demonstrated the use of Perl with a mixed mode source file in Example 5-33 on page 254. In this example, the mixed mode application uses a FileSource operator to read stock ticker information from a file. Then, it uses a Split operator to split the incoming stock tuples into one of the 26 available output ports. Each output port in the Split operator will carry stock ticker tuples starting with a particular alphabetic character. To create such a variable number of output ports, it is ideal to use a Perl loop to parameterize the output tuple definition. As you can see from the source code example above, mixing Perl with SPL is a powerful way to parameterize and add parallel operator invocations within your Streams applications. Just for illustration, the SPL code above includes three FileSink operators to log output tuples coming from three of the twenty six output ports within the Split operator.

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Example 5-33 A mixed mode Streams source file

```
namespace my.sample;

composite Main {
   type StockReportSchema = tuple <rstring symbol, rstring dateTime,
float64 closingPrice, uint32 volume>;

   graph
      stream<StockReportSchema> StockReport = FileSource() {
         param
            file: "stock_report.dat";
            format: csv;
            hasDelayField: true;
      } // End of FileSource.

      <% my $cnt=0; %>
      (<% for ($cnt=1; $cnt<=26; $cnt++) {%>
         stream<StockReportSchema> StockReportOutput<%=$cnt%>

         <% if ($cnt < 26) { %>
            ;
         <% }%>
      <% } %>)
      = Split(StockReport) {
         param
         // index: hashCode(toCharacterCode(symbol, 0) -
toCharacterCode("A", 0));
         file: "mapping.txt";
         key:  symbol;
      } // End of Split

      () as FileWriter1 = FileSink(StockReportOutput1) {
         param file: "split_ticker_output_stream_1.result";
      } // End of FileSink(StockReportOutput1)

      () as FileWriter2 = FileSink(StockReportOutput7) {
         param file: "split_ticker_output_stream_7.result";
      } // End of FileSink(StockReportOutput7)

      () as FileWriter3 = FileSink(StockReportOutput9) {
         param file: "split_ticker_output_stream_9.result";
      } // End of FileSink(StockReportOutput9)
} // End of composite Main
```


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5.4 Export and Import operators

In addition to making use of the Source and Sink operators, InfoSphere Streams applications can also communicate with each other using streams directly. This situation is achieved by using the concepts of exporting and importing streams. SPL provides two standard toolkit operators named Export and Import for this purpose.

Named streams can be imported or exported at any point in the flow.

The following two types of export and import are supported:

- Point to point
- Publish and subscribe

In the following list, we describe those two types:

- Point to point

  In point to point, one Streams application exports a stream and a second Streams application imports it.

  A stream is received by the Export operator's input port and exported using an alias output port name. The Export operator sends a stream from the current application, making it available to Import operators of applications running in the same streaming, middleware instance.

  Example 5-34 shows the output stream of a Source operator being exported. In addition, note that this stream may optionally be consumed as normal by other operators within the same application (as is the case in this example, the Sink operator also consumes the stream in the same application that exports it).

  Note that any given application can export multiple streams, but each stream must have a unique name within that application, which is a normal practice for stand-alone applications. As shown in Example 5-34, the Export operator can have one of these two optional parameters (properties that specify a tuple literal giving name-value pairs and 'streamId' as another optional parameter, of type rstring, which specifies the external name of the stream being exported).

Example 5-34 A Streams application exporting a stream

```
...
...
graph
      stream<StockReportSchema> StockReport = FileSource() {
         param
         file: "stock_report.dat";
```


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```
            format: csv;
              hasDelayField: true;
        }

           () as ExportedStream = Export(StockReport) {
              param
                 streamId: "exportedStream";
           }

           () as FileWriter1 = FileSink(StockReport) {
              param
                 file: "exported_stream.result";
           }

...
...
```

The Import operator receives tuples from streams made available by Export operators of applications running in the same streaming middleware instance. Import streams will be matched to Export streams. The match may be done by subscription / properties or by streamId name.

An imported stream is given a local stream name. This name might or might not have the same name as it had in the exported application.

Example 5-35 shows an application that imports the stream exported from the application shown in Example 5-34 on page 255. In this example, the imported stream with the name ImportedStream in the original exporting application is given the localname ExportedStream. This example reads the imported stream and saves it to a .csv file.

Example 5-35 An application importing a stream

```
...
...
graph
   ...
   ...
   stream <StockReportSchema> ImportedStream = Import() {
      param
         applicationScope: "TickerProcessing";
      applicationName: "my.sample::Main";
      streamId: "exportedStream";
   }

   () as FileWriter1 = FileSink(ImportedStream) {
      param
```


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```
        file: "imported_stream.result";
    }

...
...
```

You might want to create a source file, named `input.csv`, in the `program data` directory containing some test tuples with the format of the StockReportSchema.

If the run is successful, you should see two newly created files in the data directory: `exported_stream.result` and `imported_stream.result`, both containing identical copies of the input data. This simple example demonstrates the similar usage of both internal and exported / imported streams.

Sequential input files are commonly used for testing, as in this case, but have the disadvantage that they are finite in length. The exporting application's Source operator parameter may include initdelay=*n* seconds, which causes the Source operator to wait for n seconds before sending the data through, giving time for the importing application to fully initialize. If you launch the importing application after this time, you would not expect it to see the exported file data in this case.

You should also note that with an infinite source of tuples (as may be typical in a Streams application), the importing application could be launched at any time and it would pick up tuples from the exporter, only following the launch and initialization of the importer. If the exporting application also contained operator code that consumed the streams (as in the example), those downstream operators would not be held up waiting for the importing application to also start.

Conversely, an importing application will wait for tuples forever if a corresponding exporting application, of the required name and stream name, is never started.

Finally, even though this method is called point to point, multiple importing applications can exist, each tapping into the same exported stream.

- Publish and subscribe

  The publish and subscribe model extends the point to point model by adding the ability to associate named properties to a stream. An importing application can import streams from any application that exports streams, providing it has the properties named by the importer, as shown in Example 5-36 on page 258.

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Therefore, the publish and subscribe model removes any need for the importing application to know both the name of the application exporting the stream and the exported stream name. Instead, an importing application can connect to an exported stream of any arbitrary name coming from any application exporting it, provided it has the specified named properties.

Within the exporting application (the application publishing the stream), the export properties key-value pair is used together with a list of named properties that the designer is free to specify.

Within the importing application, the Import operator uses a subscription parameter with the required key-value pair expression.

In Example 5-36, we have two code snippets, one showing an Export operator with published properties and an Import operator with property subscription.

Example 5-36 Publishing and subscribing through Export and Import operators

```
graph
   …
   …
   () as ExportedStream = Export(SomeStream) {
      param
         properties : { call_type="outgoing",
call_mode="international",
            carriers=["Vodafone", "Telefonica", "Orange"] };
   }

   stream <SomeStreamSchema> CallTracer = Import() {
      param
         subscription: call_type == "outgoing" && call_mode ==
"international" &&
                           "Telefonica" in carriers;
   }
```

In Example 5-36, the Export operator includes the properties parameter that specifies properties of the stream as a tuple literal giving name-value pairs. In another application, the Import operator can have a subscription parameter with a list of exported stream properties in which it is interested. The Streams middleware connects the Import and Export streams if the subscription predicate matches the exported stream properties.

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5.5 Example Streams program

In this section, we describe a Streams Processing Language example that you could compile and run.

The infamous *Hello World* example program is widely accepted as originating from the book *The C Programming Language* by Kernighan and Ritchie, first published in 1978. The scenario given is that your first program in a new programming language should do something simple, such as output a message that says “Hello World".

The benefit is that to achieve this, the developer must:

- Have gained access to a development environment
- Have accessed the compiler and a properly installed development and runtime environment for the programming language concerned
- Know how to use a compatible language editor
- Be able to compile and run the software

If the program successfully runs the simple Hello World code, the developer then knows the steps taken, as well as the environment, are, at a basic level, good to use going forward to use to build more and more complex programs.

In Example 5-37, the program uses the SPL Beacon operator to generate five tuples filled with its single rstring-typed attribute, set to the string value of “Hello World”. If the program runs correctly, these Beacon-generated tuples will be received by a custom operator and displayed on the console along with the “Hello World” message(s).

Example 5-37 Hello World example

```
/*
This example is the simplest possible SPL application.
It uses a Beacon operator to generate tuples that carry
"Hello World" messages. A custom sink operator receives
the tuples from Beacon and displays it on the console.
*/
composite HelloWorld {
   graph
      stream <rstring message> Hi = Beacon() {
         param
            iterations: 5u;

         output
            Hi: message = "Hello World!";
```


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```
      } // End of Beacon.

      () as Sink = Custom(Hi) {
         logic
            onTuple
               Hi: printStringLn(message);
      } // End of Custom.
} // End of HelloWorld composite.
```

5.6 Debugging a Streams application

In this section, we describe some options and approaches for debugging a Streams application. There are nearly as many methods to debug a Streams application as there are business problems that you can solve with Streams.

The sample Streams application used in this section is listed in Example 5-38.

Example 5-38 Streams application used to demonstrate Streams debugging

```
namespace com.acme.streams.test;

composite Main {
   type
      InputSchema = tuple<int32 col1, int32 col2>;

   graph
      stream <InputSchema> InputStream = FileSource() {
         param
            file: "InputFile.txt";
            hasDelayField: false;
            format: csv;
      }

      stream <InputSchema> ThrottledInputStream = Throttle(InputStream)
{
         param
            rate: 1000.00;
      }

      () as FileWriter1 = FileSink(ThrottledInputStream) {
         param
            file: "OutputFile.txt";
            format: csv;
```


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```
    }

  config
    logLevel: debug;
}
```

Here are some considerations related to the code shown in Example 5-38 on page 260:

- The example listed is a self-contained Streams application, which means that it does not read from any imported streams, it does not export any streams itself, and it contains no references to externally defined user routines or functions.
- The Streams application reads from one operating system file (`InputFile.txt`), and outputs two columns (col1 and col2) on the Stream named InputStreams.

  This stream is consumed by the Throttle operator to control the rate and then it is consumed by a Sink operator. This Sink operator writes to an operating system file named `OutputFile.txt`.

  In effect, this Streams application is a simple file copy of every row and every column of `InputFile.txt` to `OutputFile.txt`.
- The contents of `InputFile.txt` are not displayed. Per the example, this file contains two numeric (integer) columns separated by a comma delimiter and a new-line character as the record separator.

  This file contains 10,000 records, with values ranging from 10,000 to 20,000, increasing sequentially and by a value of one. The sample contents are shown in the following list:

```
10000,10000
10001,10001
10002,10002
   … {lines deleted}
19998,19998
19999,19999
20000,20000
   {end of file}
```

- Unique to this example are two modifiers of specific interest:
  - At the end of the SPL file, you can see a configuration directive named *debug*.

    This directive allows the Streams run time to output a given level of diagnostic information to a log file on the operating system hard disk,

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specifically the Streams PE log file. (This file or files, of variable name and location, is configurable.)

Other values that may be placed in this location include trace, (debug), info, and error. Each value determines an increasing level of verbosity to the logging file contents.

– An SPL operator called Throttle will slow down the output of records from the stream named InputStream to, in effect, an output of 1000 records.

This operator would likely be removed for any production-level, Streams application, but we find the ability to slow down the execution of a Streams application to be useful when debugging.

5.6.1 Using Streams Studio to debug

The Eclipse-based Streams Studio has many visual components that enable effective debugging. To create an error condition, we misspelled the name of the operating system file shown in Figure 5-6 on page 263. It is spelled `InputFile2.txt`, but the correct name is `InputFile.txt`; `InputFile2.txt` does not exist.

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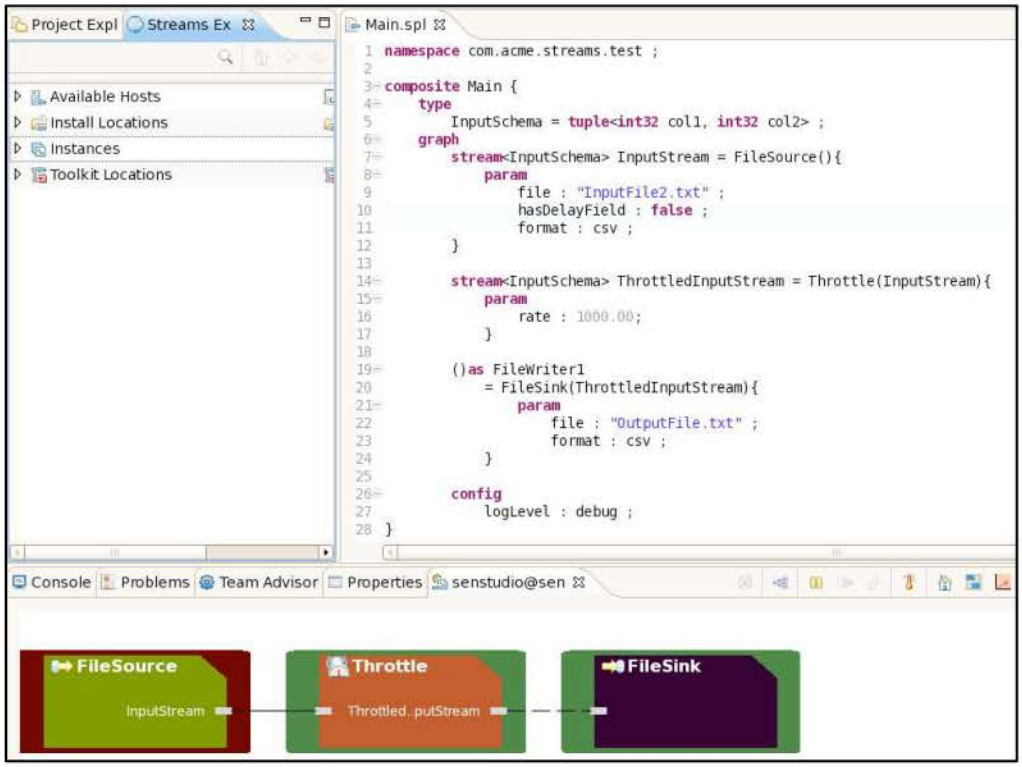


Figure 5-6 Streams Studio, Streams Live Graph - No rows being output

In Figure 5-6, we see that the Streams application is currently running. We know this because the Streams Live Graph View displays the Streams application. Also in Figure 5-6, we see there is no output from the left side operator to the one on the right side. This is because the left side operator is in a STOPPED state (red in color) and it is not outputting records because the input source file was not found. You can also notice the broken connection / dashed line between the Throttle and the FileSink operators, which also indicates no data is flowing.

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Figure 5-7 displays the Streams Live Graph View with no Streams applications running.

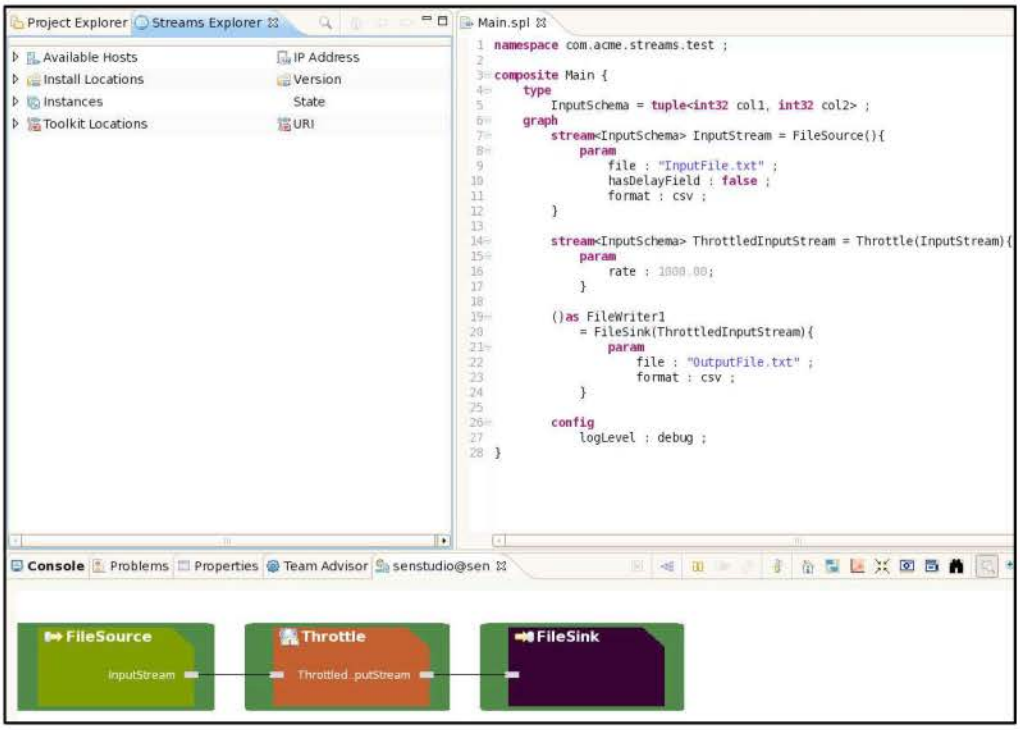


Figure 5-7 Streams Live Graph - No application running

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Figure 5-8 displays the Streams Live Graph View with the correction to the input file name. The display in the Streams Live Graph View will change color to indicate the effect of throttledRate and the various pauses and then propagation of records.

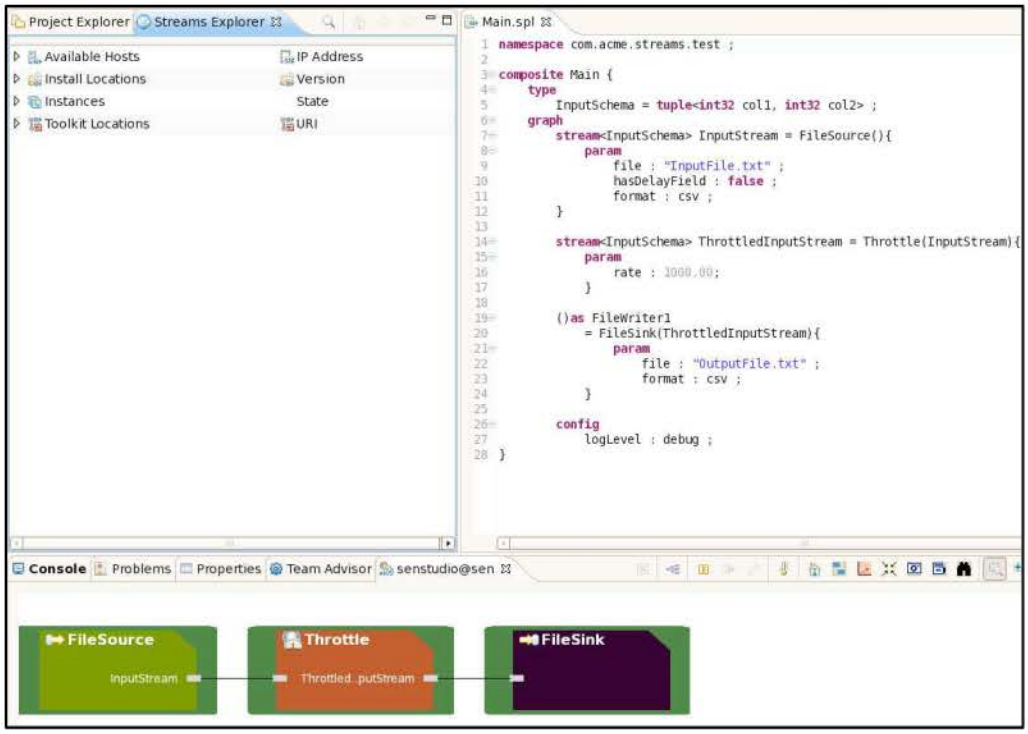
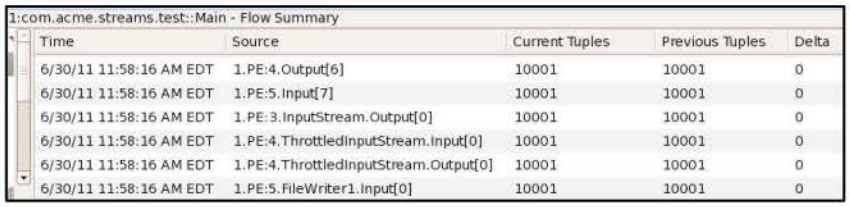


Figure 5-8 Streams Live Graph View with correction - Application running

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Figure 5-9 displays the Streams Studio, Streams Live Graph Metrics View, where you can observe the live progress of records consumed and sent down stream.


1:com.acme.streams.test::Main - Flow Summary

Time	Source	Current Tuples	Previous Tuples	Delta
6/30/11 11:58:16 AM EDT	1.PE:4.Output[6]	10001	10001	0
6/30/11 11:58:16 AM EDT	1.PE:5.Input[7]	10001	10001	0
6/30/11 11:58:16 AM EDT	1.PE:3.InputStream.Output[0]	10001	10001	0
6/30/11 11:58:16 AM EDT	1.PE:4.ThrottledInputStream.Input[0]	10001	10001	0
6/30/11 11:58:16 AM EDT	1.PE:4.ThrottledInputStream.Output[0]	10001	10001	0
6/30/11 11:58:16 AM EDT	1.PE:5.FileWriter1.Input[0]	10001	10001	0

Figure 5-9 Streams Studio - Streams Live Graph View

5.6.2 Using streamtool to debug

In Figure 5-10, we added the Streams configuration directive debugging tool to the Application-level scope. This allows us to capture runtime diagnostics from this Streams application in the Streams system log. Using the Streams command-line utility streamtool, we can now view this diagnostic output.

For this example, we return to the condition where the input text file name is not found, because the file does not exist. Figure 5-10 displays the first step in gathering this diagnostic output.

```
@a0217b10e1/~
> streamtool man
usage: man [<cmd>]

Streamtool is the InfoSphere Streams command line interface.

The other major command line tool is "sc", the Stream Processing
Language (SPL) compiler.

Streamtool consists of a number of sub-commands.  Various sub-commands
have an abbreviated name.  The command's usage infomation provided by the
"man" sub-command identifies the minimal abbreviation that can be used
to specify the command.  A '/' character in name identifies the minimal
abbreviation. Sub-command names and their option arguments are case-sensitive.
```

Figure 5-10 Using streamtool to get the list of supported commands

With respect to Figure 5-10, consider the following items:

- streamtool is a command-line utility, so each of these commands is entered at the operating system command line prompt.

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Note: The following Streams-based terms are in effect here. Keep in mind that this section serves only as a brief review:

- A Streams Instance refers to the collection of memory, process, and disk that is the Streams server proper. Each Streams Instance is identified by an Instance ID.
- The source code to a self-contained Streams application exists in one operating system text file. A Streams application is identified by its Application Name, and by its source code file name (with a .spl file name suffix).
- Streams applications are submitted to run in the form of a Streams Job. One Streams application may be running many copies concurrently. That is, running many concurrent Jobs of the same Streams application.

  Each Streams Job is identified by a unique Job ID.
- A Streams Job is a logical term, and exists as one or more operating system processes, referred to by Streams as Processing Elements (PE). Each PE has a unique PE ID.

- We ran **`streamtool man`** to get the list of available commands. For example, you can query the Streams instances created by you by running **`streamtool lsinstance`** (where lsinstance means list instance).

To get the log for a given Processing Element (PE), you need the PE ID. Figure 5-11 displays the **`streamtool`** command used to get a listing of currently executing Streams Jobs and their associated Processing Elements.

```
@a0217b10e1/"
> streamtool lspes -i senstudio
Instance: senstudio@sen
  Id State      RC Healthy Host         PID JobId JobName                    Operators
   3 Running     - yes     b0401e0     9001     1 com.acme.streams.test::Main  InputStream
   4 Running     - yes     b0405e0    24569     1 com.acme.streams.test::Main  ThrottledInputStream
   5 Running     - yes     b0405e0    24570     1 com.acme.streams.test::Main  FileWriter1
```

Figure 5-11 Getting the Processing Element IDs

In regards to Figure 5-11:

- The syntax to the **`streamtool`** command invocation above is:

```
streamtool   lspes   -i   {Instance Id}
```


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- spes, entered as one word, is short for list Processing Element IDS.
- - i is followed by the Streams Instance ID gathered using the **streamtool lsinstance command**.

► The report shown in Figure 5-11 on page 267 has a two line format.
- The Streams Job ID being tracked here is 1.
- The Streams Job has three Processing Elements, as called for by its three operators, one input, one throttle, and one output (Figure 5-11 on page 267).
- The PE ID for the FileSource operator is 3.
- If you want to view the log for the FileSource operator, which has an error in its input file name (the file is not found), then you need a method to retrieve the log for PE ID 3.

The example **streamtool** command from the continuing example is:

```
streamtool viewlog   -i   <instanceId number here>   --pe  3
```

This command invokes the configured operating system editor of your choice. An example is shown in Figure 5-12.

```
30 Jun 2011 12:24:29.695 [10133] DEBUG spl_operator M[OperatorThread.cpp:run:46]  - Operator thread created
30 Jun 2011 12:24:29.695 [10133] DEBUG PEC M[PECServer.cpp:associateThread:756]  P[6] - associating thread with peid=6
30 Jun 2011 12:24:29.695 [10133] DEBUG PEC M[PECServer.cpp:associateThread:758]  P[6] - associated thread with peid=6
30 Jun 2011 12:24:29.696 [10133] DEBUG #spllog,InputStream,spl_operator M[InputStream.cpp:process:180]  - FileSource st
artup...
30 Jun 2011 12:24:29.696 [10133] DEBUG #spllog,InputStream,spl_operator M[InputStream.cpp:processOneFile:81]  - Using '
InputFile2.txt' as the workload file...
30 Jun 2011 12:24:29.697 [10133] INFO ex M[InputStream.cpp:processOneFile:85]  - Throwing Exception: SPLRuntimeFileSour
ceOperator (Msg: Failed to open input file 'InputFile2.txt', reason: No such file or directory.)
30 Jun 2011 12:24:29.698 [10133] DEBUG spl_operator M[OperatorThread.cpp:run:75]  - Exception received during oper.proc
ess(): SPL::SPLRuntimeFileSourceOperatorException (Failed to open input file 'InputFile2.txt', reason: No such file or
directory.) at 'void SPL::_Operator::InputStream::processOneFile(const std::string&)' [src/operator/InputStream.cpp:85]

Exception Code=NoMessageId with 0 substitution text strings
```

Figure 5-12 Using streamtool to get the PE log

In regards to Figure 5-12:

► The highlighted paragraph (denoted by a rectangle) reports the condition of the input text file not being found.

► The example uses the operating system editor emacs.

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5.6.3 Other debugging interfaces and tools

A Streams application can have user-defined code written in the C/C++ programming language or code written in the Java programming language. As Streams Studio is an Eclipse-based developers workbench, which includes an embedded Java visual debugger, it is usually used by users of Streams Studio to debug Java routines. There are also third-party tools that provide C/C++ language debuggers (with similar visualization) for the Eclipse developers workbench. Programming and debugging in C/C++ or Java is not expanded upon here.

A complied Streams application exists as an operating system binary program. Using specific Streams application compilation arguments, the operating system Gdb(C) program can be used to debug Streams applications. Debugging with Gdb(C) is not expanded upon further here.

A given Streams operator can have multiple consumers of its output. For example, multiple downstream operators can consume an upstream operator's output. During the debugging phase of Streams application development, it is common to insert Sink operators merely to dump Stream contents mid-application, solely for the purpose of debugging. These command lines can be left in place, and commented out before inserting the final Streams application into production.

Note: It is particularly useful to use the above technique to create redundant (test only) Sink operators when working with Streams Functor operators.

With the Streams Debugger, it is extremely easy to evaluate input and output records and columns to a given Streams operator. However, seeing inside a given Functor operator, and more specifically its flow control and variable assignments, is another challenge.

5.6.4 The Streams Debugger

Given the volume of information that has been written related to debugging a Streams application, you might think that there was not a debugger to be found inside the Streams product. However, this is not the case. The Streams Debugger is currently documented in *IBM InfoSphere Streams SPL Streams Debugger Reference*, which can be found at:

`http://publib.boulder.ibm.com/infocenter/streams/v2r0/index.jsp`

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