A Productive Programming Environment for Stream Computing

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Abstract

This paper presents StreamIt and the StreamIt Development Tool. The development tool is an IDE designed to improve the coding, debugging, and visualization of streaming applications by exploiting the ability of the StreamIt language to naturally represent streaming codes as structured, hierarchical graphs. The StreamIt Development Tool aims to emulate the best of traditional debuggers and IDEs while moving toward hierarchical visualization and debugging concepts specialized for streaming applications. As such, it provides utilities for stream graph examination, tracking of data flow between streams, and deterministic execution of parallel streams. These features are in addition to more conventional tools for creating and editing codes, integrated compilers, setting breakpoints, watchpoints, and step-by-step program execution.

A user study evaluating StreamIt and the development tool was held at MIT during which participants were given erroneous programs and asked to resolve the programming errors. We compared the productivity of the users when using the StreamIt Development Tool and its graphical features to those who were restricted to line-oriented debugging strategies, and we found that the former produced ten more correct solutions compared to the latter set of users. Furthermore, our data suggests that the graphical tool chain helped to mitigate user frustration and encouraged participants to invest more time tracking and fixing programming errors.

1 Introduction

The last few years have witnessed the rebirth of supercomputing as computer scientists and engineers realize that current monolithic architectures and conventional von Neumann programming styles are at their limits in terms of deliverable performance to the end-user. Thus as architects, compiler engineers, and application developers look into the future, there is a concerted effort to develop processors and programming paradigms that can deliver significantly better performance, and more so, to deliver high performance more productively. This is especially important since the complexity of applications continues to increase, and compilers are more heavily burdened with the extraction of parallelism and the efficient mapping of computation to physical substrate. What's more is that the architectures of the future will tend toward distributed resources in an effort to manage the complexity of centralized architectures with respect to power and wire delay. Thus, research labs in industry and academia alike are investigating ideas and methodologies to address the computing challenges of the future with an eye toward delivering high performance and to do so productively. This goal translates to (i) relieving application developers from architecture details and allowing for natural expression of applications, (ii) lessening the burden for heroic compilers that extract parallelism, (iii) developing scalable architectures that are powerful yet easier to verify and assemble.

The Computer Architecture Group at MIT has for the last several years conducted research to address all of the aforementioned objectives. This paper focuses on the productivity of application developers. Specifically, the paper will briefly describe StreamIt [11] a novel language for the prevalent application class of stream computing. StreamIt provides high-level stream abstractions that improve programmer productivity and program robustness. The language is architecture independent, and it features several characteristics (such as parameterization and modularity) geared toward large scale program development. Furthermore, this paper will also describe a unique development environment that leverages the language features to deliver a tool chain for the rapid verification and debugging of StreamIt programs.

StreamIt represents a program as a hierarchical graph of concurrent filters that operate on streams of data and communicate via FIFO queues. The language exposes the parallelism and communication patterns that are inherent in many streaming programs which include software radio, real-time encryption, network processing, graphics, and multimedia editing consoles. Because of the abundance of parallelism in such applications, they are especially challenging to program, and worse, to debug. This is due to the multitude of factors that an application developer must consider when implementing a streaming program, such as for example how to exploit the parallelism on a target architecture. The marriage of implementation to a specific processor results in both algorithmic changes and code transformations that make porting difficult—since the transformations depend on the architecture details.

By contrast, application developers using StreamIt focus on specifying the functional behavior of their programs and verify correctness using high level abstractions that result in clean and portable implementations. The task of optimizing the code and efficiently mapping it to target processors is left to the compiler which can automate many powerful domain specific optimizations to deliver high performance [5, 9]. This paper will not discuss the StreamIt compiler technology; the interested reader can visit the StreamIt web page [10] for more information on the topic.

In addition to the language and compiler effort, we have engineered and developed a programming environment that graphically represents the hierarchical nature of streaming codes with an eye toward the productivity of the application engineer. The StreamIt Development Tool (SDT) provides an elaborate prototyping and debugging environment that can interpret and visually represent streaming computation. The key distinguishing features of the SDT are its ability to track the flow of data between streams, and the deterministic execution of parallel streams. The latter leverages an intuitive concept of time in StreamIt that is tied to the flow of data in distributed programs. A significant portion of this paper is dedicated to evaluating the SDT and its impact on programmer productivity. Toward quantifying productivity, we organized a user study at MIT. The study involved a number of students who were given a set of "buggy" applications and asked to fix the codes according to corresponding functional specifications. Some of the study participants were allowed to use the graphical debugger and its distinguishing features, whereas others were restricted to line-oriented debugging strategies. The results of our study provide evidence that the SDT was instrumental in helping the users track down and repair programming errors. The evidence is particularly strong in cases where the applications were large, with many streams and non trivial communication topologies.

As we analyzed the data from the user study, we made a somewhat surprising observation. First, it was evident that the SDT did not make users faster. In fact, the mean time to solution (i.e., a program where all of the bugs are fixed) was longer for participants using the graphical debugger. Perhaps this is to be expected since the participants did not have prior experience with the language or the IDE, and indeed our post-study interviews and feedback support this theory. Second, the data suggested that the power of the SDT is in mitigating the frustration factor of the participants, especially in the later portions of the study. That is, the participants who were restricted to line-oriented debugging strategies gave up more often, and did so sooner, compared to their counterparts using the graphical debugger. This led us to conclude that users tend to be more productive when they trust the tools at their disposal. In other words, one might believe their probability of success is reasonably high if they are confident that the tools they are using are adequate, and therefore they are more likely to invest their time objectively.

In the following Section we describe the StreamIt programming language, and in Section 3 we describe the StreamIt development environment. Section 4 describes our user study and reports our results and analysis. Section 5 summarizes related work and Section 6 concludes the paper.

2 The StreamIt Programming Language

StreamIt is an architecture-independent language for streaming applications. It adopts the Cyclo-Static Dataflow [1] model of computation which is a generalization of Synchronous Dataflow [7]. StreamIt programs are represented as graphs where nodes represent computation and edges represent FIFO-ordered communication of data over tapes.

The basic programmable unit in StreamIt is a filter. Each filter contains a work function that executes atomically, popping (i.e., reading) a fixed number of items from the filter's input tape and pushing (i.e., writing) a fixed number of items to the filter's output tape. A filter may also "peek" at a given index on its input tape without consuming the item; this makes it simple to represent computation over a "sliding-window". The push, pop, and peek rates are declared as part of the work function, thereby enabling the compiler to construct a static schedule of filter firings [6].

StreamIt provides three hierarchical structures for composing filters into larger stream graphs (see Figure 1). The *pipeline* construct composes streams in sequence, with the output of one connected to the input of the next. The *splitjoin* construct distributes data to a set of parallel streams, which are then joined together

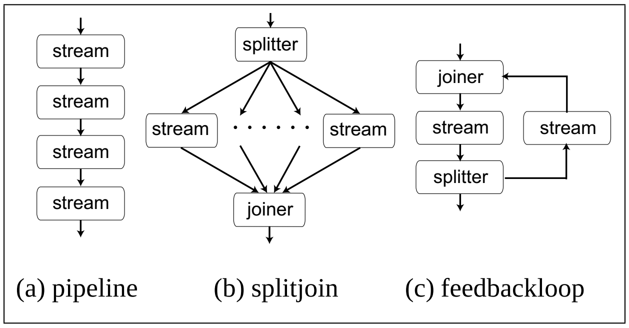


Figure 1. StreamIt containers.

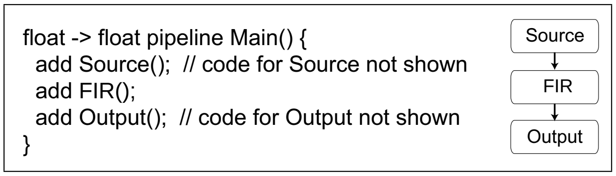


Figure 2. Example pipeline with FIR filter.

in a round robin fashion. The *feedback loop* provides a mechanism for introducing cycles in the graph. An example of a pipeline appears in Figure 2. It contains a single FIR (Finite Impulse Response) filter which could be implemented as follows:

```
float->float filter FIR (int N, float[] weights)
{
  work push 1 pop 1 peek N {
    float sum = 0;
    for (int i = 0; i < N; i++) {
      sum += peek(i) * weights[i];
    }
    pop();
    push(sum);
  }
}
```

The filter can now serve as a module that is incorporated into stream graphs as necessary, for example as part of an acoustic beam former. A filter is akin to a class in object oriented programming with the work function serving as the main method. A filter may also declare a constructor function to initialize the filter state before any other method is invoked. The implementation of the work function in StreamIt obviates the need for explicit buffer management. The application developer instead focuses on the hierarchical assembly of the stream graph and its communication topology.

3 Development Environment

The StreamIt Development Tool (SDT) features many aspects of an IDE, including a text editor and a debugger. For example, the SDT debugger supports line and method breakpoints, watchpoints, program suspension, code stepping, variable inspection and value modification to list a few.

Moreover, the SDT offers features tailored to the StreamIt language. The SDT graphically represents StreamIt programs, and preserves hierarchical information to allow an application engineer to focus on the parts of the stream program that are of interest. In addition, the SDT can track the flow of data between filters, and most importantly, it provides a deterministic mechanism to debug parallel streams.

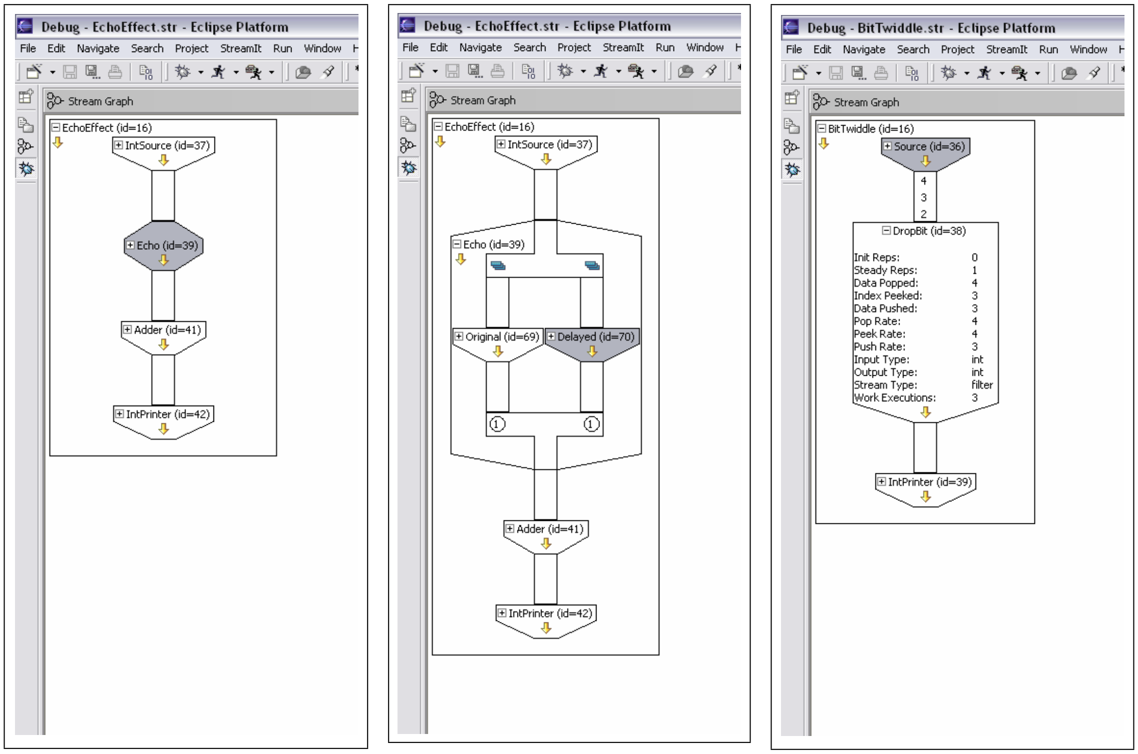
The SDT is implemented in Java as an Eclipse [3] plug-in. The Eclipse universal tools platform is an extensible development environment. We leverage the built-in user interfaces for editing and viewing files, the resource management system, the documentation infrastructure, and the runtime support of launching, running and debugging programs.

3.1 Hierarchical Graphs

As seen in Figure 3, a StreamIt program can be visually depicted as a hierarchical directed graph of streams, with graph nodes representing streams and graph edges representing tapes or channels. The containers are rendered according to the code declarations, and the visualization tools in the SDT allow the user to selectively collapse and expand containers. This is useful in large streams where the application developers are only interested in visualizing a particular subset, for example to verify the interconnect topology of the graph. In Figure 3(a), we show a screen shot of the SDT for a simple StreamIt program which consists of a filter that generates input data (`IntSource`), a splitjoin (`Echo`) that operates on the data produced by the source and whose data is in turn consumed by an `Adder`. Lastly, a filter (`IntPrinter`) reads and prints the computed values to the screen. In Figure 3(b), the splitjoin is expanded to reveal to parallel streams: `Original` and `Delay`. The former is simply an identity filter, whereas the later shifts its input data one position in time (i.e., at time t it outputs data consumed at time $t + 1$. The splitter in this example is a duplicate splitter, meaning that the input stream is duplicated to all of its siblings. The joiner is a roundrobin joiner which collects one data item from the left stream followed by an item from the right stream. This particular stream program simulates how echos are added to sound waves.

3.2 Data Flow

An important distinguishing characteristic of the SDT is its ability to track the flow of data between



(a) Collapsed pipeline.

(b) Expanded splitjoin.

(c) Example pipeline with data in transit.

Figure 3. Hierarchical stream graph views.

streams. This is illustrated in Figure 3(c) which shows the data that is live between two filters `Source` and `DropBit`. This particular program generates a sequence of numbers at its source, and the `DropBit` filter removes the third element of the sequence with every execution of its main function. In the figure, the values 2, 3, and 4 are queued on the input tape to `DropBit`, and from the expanded filter node, we can see that the filter requires four queued data items before the work function can execute (i.e., the declared pop rate is 4). The expanded filter node also displays other information such as the input and output types of the stream, as well as profiling information that is useful for debugging.

The SDT also allows the user to highlight and automatically track data items as they propagate between streams. The user can also modify values on a tape, much like a conventional debugger allows users to modify variables and registers.

The flow of data is especially helpful in splitjoins where sequential data streams are distributed to parallel streams, and parallel streams assembled into a single stream. The visualization allows the user to readily verify that splitters and joiners implement the desired functionality. Also, the visualization allows users to quickly pinpoint unexpected outputs (e.g., a filter pushing NaN's).

3.3 Debugging Parallel Streams

Perhaps the most important feature of the SDT is its support for debugging parallel streams. In StreamIt, the streams in a splitjoin are independent, and can execute when their corresponding data are queued. Thus, the SDT can execute parallel streams in a deterministic order using a single program counter and machine state; this is in contrast to a multi-threaded program where a user has to cope with multiple program counters and a scheduling order that may appear non-deterministic and subject to the host operating system. Furthermore, by exposing the flow of data and the communication in a stream graph, StreamIt provides a natural way to reason about time in a distributed system—thereby greatly simplifying the task of debugging parallel streaming programs.

The SDT also features a unique capability that allows a user to set instance-breakpoints. This features is useful in splitjoins with many parallel streams or in long pipelines which contain multiple instances of a single filter. As with conventional debuggers, the program executes until the designated instance of a filter is encountered—in which case control is transfered to the user for further input.

4 Productivity Study

We designed and carried out a user study to assess the extent the SDT helps in debugging StreamIt programs. The goals were two fold. First, we aimed to identify difficulties in using the SDT and toward this end we used questionnaires and automatic action logging. The second goal was to gather data to support the hypothesis that the SDT can improve a programmer's ability to debug StreamIt applications.

We provided participants with a set of "buggy" StreamIt programs, along with verbal descriptions of the programs. The participants were asked to find and fix the errors and to record their experience using various forms and questionnaires. The participants were divided into different groups, some of which used the SDT and its graphical debugging features whereas others did not. Our results and analysis are reported in the following sections.

4.1 Target Population

We solicited participants for the user study by advertising it to MIT students majoring in computer science. We favored students who specialize in communications, signal processing, computer systems and architecture, and who are experienced in popular imperative languages (e.g., C, C++, Java). The nature of study was not explicitly divulged in our solicitation; this served to prevent potential users from learning about StreamIt and becoming familiar with the SDT prior to the study. The participants were awarded a small monetary gift upon completion of the study.

4.2 Methodology

Each participant in the user study was presented with a set of documents that described the tasks of the study and which served to record information from the participants during the study. The documents were:

1. Pre-Study Questionnaire: This document was designed to gather information on the participant's programming background and skill level. Questions such as year in school, major, degree being sought, area of computer science concentration, relevant classes, language proficiency, application development experience, and background in DSP, IDE, and the SDT were asked.

2. StreamIt Language Tutorial: This written presentation was intended to give a cursory introduction to the StreamIt language. It described and illustrated the syntax and semantics of the StreamIt language. Furthermore, example toy applications and tips on the most common mistakes new StreamIt programmers are likely to make were included.

3. SDT Tutorial: Another written presentation, this document was aimed at informing users of the essential features of the SDT. The first part of the tutorial described the functionality of the StreamIt editor and debugger. The second part of the document contained step-by-step instructions on how to compile, run, and debug a sample application.

4. User Tasks: This document instructed users to debug nine StreamIt applications in a specific order. Each of the nine programs contained one or more bugs. As the users moved from one program to the next, they were asked to record their start and end times, the debugging methods they used (e.g., code inspection, print statements, graphical debugger), and a short diagnosis of the program bugs they uncovered.

5. Description of Applications and Code: This document contained a description of each application (numbered 1 through 9), a code listing, a sample buggy output, and a sample correct output. The applications are summarized in Table 1.

6. Post-Study Questionnaire: This document was designed to gather data pertaining to the participant's experience, such as the perceived difficulty of each problem, a general description of how the user debugged each application, user satisfaction, ability to learn and recall various features of the SDT, etc.

In order to minimize biased effects on a programmer's debugging ability, and to ensure internal validity, users were grouped into four categories. All users were asked to debug application 1 without the SDT's graphical features. The participants were then asked to debug application 2 using the SDT and its graphical features. These "control" experiments served to create a baseline

Table 1. Applications used in the productivity study.

1. Bit Twiddle	Removes every third bit from a 96 bit stream.
2. Fib	Generates a Fibonacci sequence using a feedback loop.
3. Echo Effect	Simulates how echos are introduced into sound waves. Uses a splitjoin with two parallel streams.
4. Merge Sort	Implements a merge sort algorithm using 16 parallel streams.
5. Cornerturn	Implements a matrix transpose using a splitjoin to exchange the rows and columns. Stresses the visual tracking of data.
6. Echo Effect2	Alternate implementation of Echo Effect using a feedback loop.
7. Bubble Sort	Implements a bubble sort algorithm. This is a conceptually difficult implementation that stresses the visualization features of the debugger.
8. Bit Reverse	Sorts a sequence of 16 consecutive numbers in bit-reversed order. This is an adaptation of the bit-reversal stage in FFT.
9. Overflow	A synthetic benchmark with a substantial number of hierarchies, filters, and parallel streams. Stresses the visual tracking of data, and the instance breakpoint capabilities of the debugger.

reference for meaningful comparison later on[1]. Moreover, the control applications were designed to bolster the user's confidence. Next, half of the users (group A) were told to debug applications 3, 4, and 5 with the SDT and 6, 7, and 8 without the SDT (i.e., using the graphical features of the SDT then without the graphical features). Meanwhile, the other half (group B) were told to debug 3, 4, and 5 without the SDT and 6, 7, and 8 with the SDT. Due to this grouping structure, applications 3 and 6, 4 and 7, and 5 and 8 were designed to be of comparable difficulty. For application 9, half of group A (A1) and half of group B (B1) were asked to debug with the SDT, while the other halves (A2 and B2) were asked to debug without the SDT. Cross-sectioning the groups was aimed at ensuring external validity.

The study was divided into three sessions over a three-day period. We estimated that each session would last for two hours (with 45 minutes spent on the tutorials and the rest of the time dedicated to debugging), but in reality the sessions spanned an average of four hours. Many users were either unable or did not have enough time to debug certain applications. Participants were asked to complete the set of documents at their own pace, and upon completion, they were individually interviewed and received a $40 gift certificate. During the study, users were encouraged to ask questions although particulars relating to the problems and the SDT were not revealed.

[1]The control experiments served mainly to filter data. We did not use data attributed to participants who did not complete the control experiments.

4.3 Results and Analysis

Even though 25 users were scheduled to participate (5 people for sessions 1 and 2 and 15 people for session 3), cancellations reduced the participation to 20 users and led to uneven groupings. There were 6 people in A1, 5 in A2, 4 in B1, and 5 in B2. Of the 20 participants, there were 4 juniors, 2 seniors, 8 masters, and 6 Ph.D. students, all majoring in Electrical Engineering and Computer Science. None of the users had prior StreamIt or SDT experience.

Figure 4 summarizes the study in terms of the number of solutions reported for each of the applications in the study. In the figure, the bars labeled "solved with the SDT" represent the number of participants that fully debugged the corresponding applications using the SDT and its graphical features. Similarly, the bars labeled "solved without the SDT" represent the number of participants that fully debugged the corresponding applications without using the graphical debugger. The bars that are labeled "unsolved" represent the number of participants whose applications remained buggy. For example, for the application `EchoEffect` there were two users who were allowed to used the SDT and were unable to debug the code properly. There was also one other participant who did not debug `EchoEffect` although this user was not allowed to use the SDT's graphical features.

Because the groupings are uneven as previously mentioned, the numbers seen in the figure are weighted depending on which group is lacking users. The percentage above each quadruple of columns represents the percentage increase or decrease in debugged applications due to the SDT (and its graphical features). For example, the graphical debugger did not particularly help in appli-

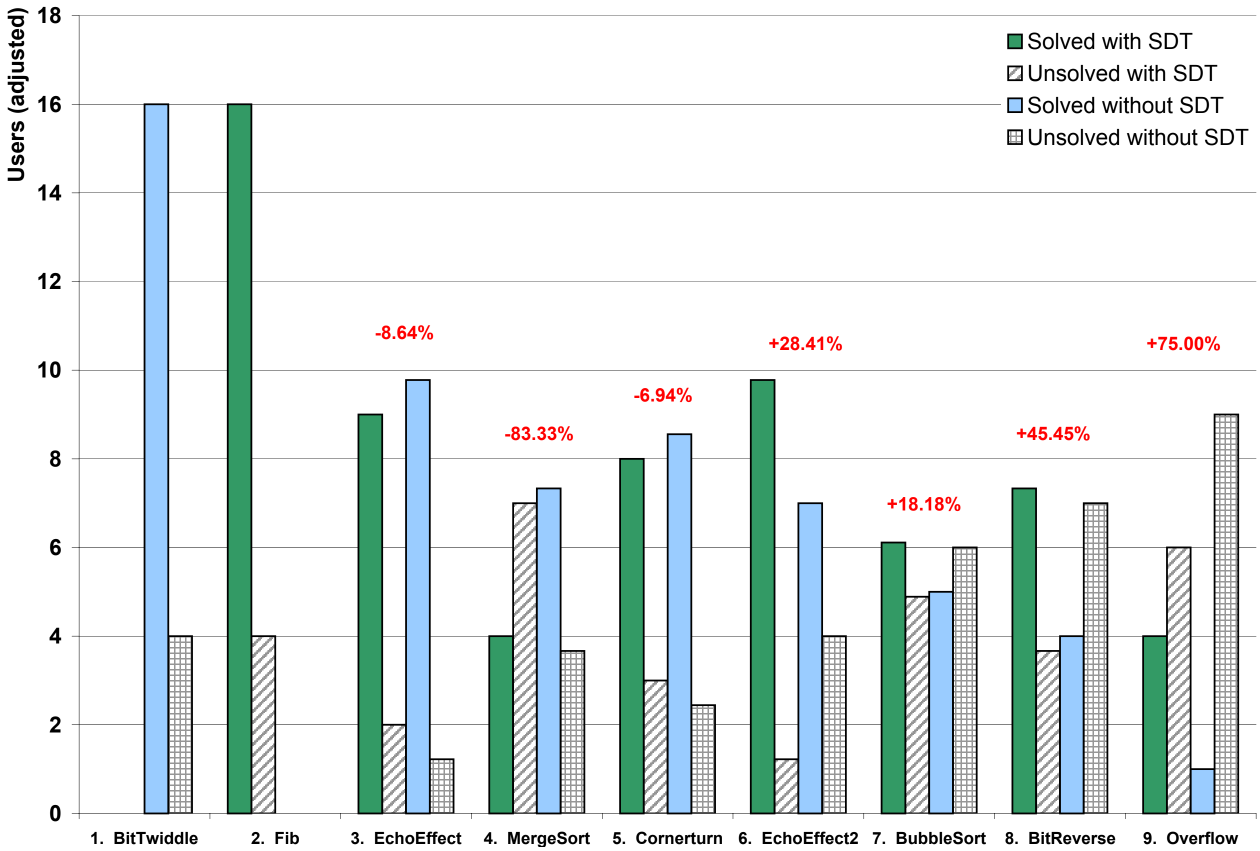


Figure 4. Summary of results.

cations 3, 4, and 5, but did help in debugging the others. On average, 1.56 fewer participants fully debugged applications 3, 4, and 5 when using the graphical debugger, and 2.56 more users debugged applications 6, 7, 8, and 9 when using the graphical debugger.

Figure 5 compares the average time spent debugging each application. The percentage above each set of columns represents the percentage improvement or deficiency in time caused by using the SDT. On average, users took 7.78 (36.48%) more minutes to debug applications 3, 4, 5, 6, 7, and 9 when using the graphical features of the debugger, compared to participants using more traditional debugging means. Furthermore, participants who were allowed to use the SDT and its graphical features spent an average of 16.96 more minutes debugging applications 6, 7, and 8, compared to an average of 10.67 minutes invested by the participants who could not use the graphical debugger. In both cases the participants did not fully debug their respective applications.

Summarizing the results, we found that more participants were able to successfully debug their applications when using the SDT and its graphical features. However, we also observed that the SDT increased the "time to solution" as users had to navigate through a user interface they were not familiar with. Interestingly, we can also observe that the SDT may have mitigated user frustration. As noted earlier, users generally spent much more than the two hours allotted to complete the study, and as such, users became frustrated and may have rushed with the later applications. Correspondingly, this might have caused users to spend less time and debug fewer applications as users progressed through the study. Although this pattern is true for participants who did not use the SDT, the opposite occurs for participants who used the SDT: 41.76% more users were able to debug applications 6, 7, 8, and 9 using the SDT. Furthermore, users spent 83.35% more time tracking down bugs in applications 6, 7, and 8 when using the graphical debugger. These results suggest that users are willing to spend more time and work on more problems when using a tool that they felt more certain would lead them to a solution.

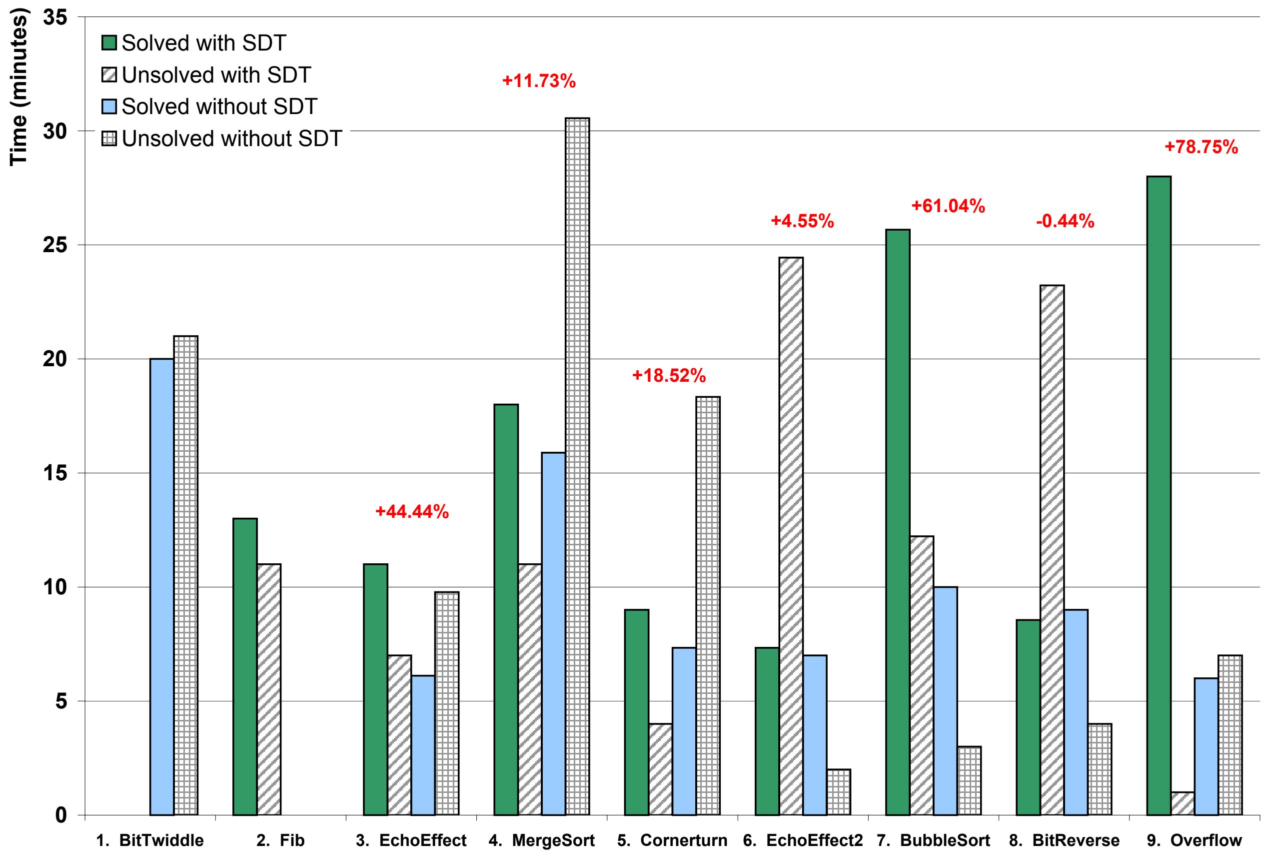


Figure 5. Summary of results.

4.4 User Feedback

Comments obtained from the post-study questionnaires were quite helpful toward finding new feature ideas and problems with functionality, performance, reliability, and usability.

Summarizing the most notable feedback, users largely commented on their difficulties using Eclipse and navigating the StreamIt code. Ten participants reported that the time alloted to learn how to navigate Eclipse was too short, and that the many windows, menus, and options made it difficult to find vital information quickly. Five participants noted that they were uncomfortable or unaccustomed to thinking in terms filters and streams, while an equal number also found it overwhelming to remember some of the language syntax and concepts.

In general however, participants rated the SDT a 3.85 on average (on a scale of 1 to 10, from easy to hard), praising many aspects of the stream graph viewer (e.g., hierarchical representation). Those who rated the SDT as helpful, stressed that it was most useful for graphically visualizing the flow of data in the programs, especially when the applications were large.

4.5 Discussion

Many problems and issues arose in running the study itself. One of the major problems was the time allotted for users to complete the study. As previously mentioned, the slowest user spent twice the budgeted amount of time. The timing negatively impacted users in several ways, all of which contributed to incomplete or unreliable data: Users became frustrated and overwhelmed by the amount of information presented to them; Users were unable to complete the study due to time constraints; Users did not properly fill out the post-study questionnaire, etc.

We believe that better screening can help bridge the gap between between participants, although the biggest lesson learned centers on the method of compensating the participants. Specifically, a multi-level pay scale for compensation may have alleviated some of the above problems and lead to more conclusive results. A graded pay scale would allow each participant to judge whether they can or are willing to complete the study. In other words, each user is rewarded according to their investments. Nonetheless, the expertise gap between participants in a user study is a well-documented issue: Usability studies have found that the best users are often ten times better than the worst users, and the fastest quartile of users are twice as fast as the slowest quartile of users [2, 8]. However, because increasing the number of users in a study only narrows the standard deviation of the mean by the square root of the number of users[2], the improvement in results and reliability becomes an expensive and time-consuming task. For example, in order to double accuracy, the number of participants in this study would have to be quadrupled to 80 users, which would cost an additional $2400 and 24 man-hours.

5 Related Work

Numerous debuggers and program visualization tools exist for DSP applications written in C/C++ and assembly. The majority of these tools are targeted at specific hardware platforms, offering traditional debugging features (i.e., program suspension, breakpoint stepping, watchpoints, local variable and output display, etc.) combined with assembly code, memory register, and signal plot display.

In recent years, some movement in the streaming domain has been made toward OOP languages such as C++ or Java, which introduce abstractions that improve the portability and reusability of code. The introduction of conceptual abstractions empowers the design, debugging, visualization, and analysis tools created for OOP based streaming applications to introduce hierarchical, modular structures while hiding unnecessary details from the programmer. On top of the traditional debugging features previously mentioned, all three of the tools described next use some variation on the theme of signal processing blocks that are connected, displayed, and navigated graphically.

Simulink is a modeling, simulation, and analysis tool for control, signal processing, and communications system design. This tool imposes OOP conventions on Matlab, C, Fortran, and Ada programmers by allowing its users to insert their code into the methods of predefined blocks or to use application-specific standard block libraries. Furthermore, hierarchically block navigation at both the design and debugging stages is offered: command-line Simulink Debugger enables breakpoint stepping of the currently executing method which is simultaneously displayed on its associated block. Additional information, such as block state, inputs, and outputs, are visible in other windows.

Process-Level Debugger (PDG) is designed for a graphical parallel programming environment for concurrent applications called GRAPE. The PDG models processes as black boxes that interact with each other. Like Simulink, programmers build their applications by creating and connecting black boxes hierarchically (i.e., each black box may be composed of sub-boxes–subprocesses–and displayed in a graphical view). As an application is debugged, the PDG shows the application's behavior in a window and allows a programmer to zoom down on suspicious process blocks in the hierarchy. This top-down debugging method can eventually find the associated erroneous code.

The MULTI Integrated Development Environment is designed for multiprocessor, distributed systems and embedded applications using C, C++, Ada, Fortran, and assembly. Besides standard editing and debugging functionality, this IDE conveys program control flow with perusable static and dynamic call graphs and class hierarchies.

Much like other language efforts, StreamIt addresses many software engineering concerns by embracing concepts such as modularity, parameterization, hierarchical composition, and portability. Furthermore, the language automates several tedious tasks such as circular buffer management that is common in streaming codes. StreamIt also facilitates the verification of program via inductive reasoning since simple components are assembled to create large and complex graphs. Moreover, the language treats communication and parallelism as "first-class citizens", and by naturally exposing the flow of data in a program, the StreamIt Development Tool can help application engineers in their debugging and verification tasks.

A more thorough treatment of related work is available [4] for review by the interested reader.

6 Concluding Remarks

This paper presents StreamIt and the StreamIt Development Tool. The SDT is an IDE designed to improve the coding, debugging, and visualization of streaming applications by exploiting the StreamIt language's ability to naturally represent these applications as structured, hierarchical graphs. Although industry and academia have devoted much effort to tools for developing and debugging software, the SDT aims to emulate the best of traditional debuggers and IDEs while moving toward hierarchical visualization and debugging concepts specialized for streaming applications. As such, it provides utilities for stream graph examination and navigation, and detailed tracking of data between streams, as well as deterministic execution of parallel streams. These features are in addition to program creation and code editing, program compilation and launch support, and general debugging and help support.

A user study evaluating the SDT uncovered several problems and areas of improvement that need to be addressed before this tool can fully realize its goals. From the user study however, we have empirical evidence to suggest that the SDT improved the ability of users to find and repair programming errors. The user study also provided key insights that suggest that application developers and engineers are more likely to invest their time tracking bugs and enhancing their applications if they are confident they have adequate tools at their disposal. In our user study, several subjects using the StreamIt graphical debugger spent considerable more time debugging applications in the latter parts of the study, compared to subjects who were restricted to line oriented debugging.

For more information on StreamIt, or to download the StreamIt compilation and development infrastructure, please visit the project web page [10].

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