

# Incorporating Scheme-based Web Programming in Computer Literacy Courses

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## Abstract

We describe an approach to introducing non-science majors to computers and computation in part by teaching them to write applets, servlets, and groupware applications using a dialect of Scheme implemented in Java. The declarative nature of our approach allows non-science majors with no programming background to develop surprisingly complex web applications in about half a semester. This level of programming provides a context for a deeper understanding of computation than is usually feasible in a Computer Literacy course. The course does not require the students to download any software as all programming can be done with Scheme applets. The instructor however must provide a Scheme server which will run the students' servlets.

## 1 Introduction

There are two general approaches to teaching a Computer Literacy class. The most common approach is a broad overview of Computer Science including hardware, software, history, ethics, and an exposure to industry standard office and internet software. On the other end of the spectrum is the class that focuses on programming in some particular general purpose language, (e.g. Javascript [11], Scheme[5], MiniJava[10]).

The primary disadvantage of the breadth-first approach is that it tends to offer a superficial view of computing. The depth-first programming approach on the other hand often requires a substantial effort just to learn the syntax of the language and the semantics of the underlying abstract model of computation, leaving little time to look at other aspects of computing such as internet technology or computer architecture.

Several authors have recently proposed merging these two approaches by using a simpler programming language (e.g. Scheme[5], [6]) or by using an internet-based

programming language (e.g. Javascript[11], MiniJava[10]).

In this paper we describe a five year experiment in combining these two approaches in a Computer Literacy course at Brandeis University (CS2a: Introduction to Computers). This course teaches programming concepts using a small (but powerful) subset of Jscheme[2] – a Java-based dialect of Scheme. The tight integration of Java with Jscheme allows it to be easily embedded in Java programs and hence makes it easy for students to implement servlets, applets, and other web-deliverable applications. Jscheme is an implementation of Scheme in Java (meeting almost all of the requirements of the R4RS [4] Scheme standard). It also includes two simple syntactic extensions:

- **javadot notation:** this provides full access to Java classes, methods, and fields
- **quasi-string notation:** this simplifies the process of generating HTML.

The javadot notation provides a transparent access to Java and the quasi-string notation provides a gentle path from HTML to Scheme for novices. It also provides a convenient syntax for generating complex strings of other sorts (such as SQL queries). These two extensions will be discussed at length below.

Jscheme can be accessed as an interpreter applet (running on all Java-enabled browsers) or as a Java Network Launching Protocol (JNLP) application. Both of these provide one click access to the Jscheme IDE from standard browsers. It can also be downloaded as a jar file and run from the command line as a standard read-eval-print-loop program.

Jscheme has been built into a Jakarta Tomcat webserver as a webapp which allows students to write servlets and JNLP applications directly in Jscheme. This webserver typically runs on the instructor's machine, but students can easily download and install the server on their home/dorm PCs as well.

In the sequel, we explain, in detail, how Jscheme can be used to teach non-science majors in a large lecture class

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how to build servlets and applets in a six week section of a Computer Literacy course. The approach described here is very similar to the approach used in the Autumn 2001, “Introduction to Computers” course at Brandeis University, but it reflects changes that will be incorporated in the next year’s version of the course. The course and the underlying language have been evolving steadily over the past five years and will likely continue to do so.

This approach to teaching Computer Literacy is feasible because of the declarative style of programming that is possible in Scheme, together with the extremely simple syntax and semantics of Scheme.

We posit that this web-programming based approach would work with other declarative languages (e.g. Haskell or Prolog), but would be infeasible with imperative languages such as Java or Perl. Scheme however is ideally suited to this application because of the relative simplicity of its syntax and semantics, both of which can be stumbling blocks for novice programmers.

Although the particular languages and techniques that we use may not be the best match at other institutions, we feel that the general approach could be easily replicated using other languages provided care is taken to make the syntax and semantics that must be learned as simple as possible.

## 2 Related Work

The need for a simple, but powerful, language for teaching introductory CS courses has been discussed recently by Roberts [10] who argues for a new language, Mini-java, that provides both a simpler computing model (e.g. no inner classes, use of wrapper class for all scalar values, optional exception throwing) and a simpler runtime environment (e.g. a read-eval-print loop is provided). Jscheme can be viewed as an even more radical simplification of Java in that it replaces the syntax of Java with the syntax of Scheme (matching parentheses and quotes is the only syntactic restriction) while maintaining access to all of the classes and objects of Java.

Another recent approach for introductory courses is to use Javascript to both teach programming concepts and to provide a vehicle for discussing other aspects of computing such as the internet and web technology. For example, David Reed proposes teaching a course [11] in which about 15% of class time is devoted to HTML, 50% to Javascript, and 35% to other topics in computer science. Our approach follows a similar breakdown but also allows the students to build servlets, applets, and GUI-based applications.

A third related approach is to teach Scheme directly as a first course. The MIT approach, pioneered by Abelson and Sussman [1], is not suitable for non-science majors

as it requires a mathematically sophisticated audience.

A gentler introduction to Scheme[5],[6] has recently been proposed which is appropriate (and in fact important) for students in all disciplines. This course has as its goal teaching almost all of the Scheme language in an introductory course. This leaves little time is left for other topics (e.g. computer architecture, chip design, internet programming, ethical and legal issues in computing), but that can be a worthwhile tradeoff.

We provide an introduction to only a subset of the language (for example, introducing lists only toward the end). We start by introducing some high-level declarative libraries for teaching an event-driven model of GUI construction. The Scheme section of the course requires only about 6 weeks. This leaves half of the course for standard Computer Literacy topics.

## 3 Goals, Syllabus, and Rationale

Our main goal in teaching a Computer Literacy course is to help the students gain a broad understanding of digital computation. It is our feeling that Computer Literacy courses are most effective if they focus on the fundamental mechanisms of computing at all levels and if they ground this theoretical material by requiring the students to build programs using these fundamental concepts.

The syllabus covers the mechanisms underlying CMOS gates and VLSI, the structure and interpretation of assembly language, the design of simple GUI-based applications, the mechanisms underlying servlets (including counters, logs, and auto-generated email), the basic design and structure of the internet, and the limits of computers (e.g. the Halting problem and the Turing test).

We test their understanding of this material using weekly quizzes, biweekly homework assignments, and a final exam in which they must write and/or trace programs at these various levels (from semiconductors to servlets). Before delving into a detailed description of the curriculum we first explain what we do not cover and provide some justification for these choices.

We deviate from many Computer Literacy courses in that we spend very little time discussing the standard application programs (e.g. word processors, spreadsheets, email, instant messaging, file sharing, image processing etc.) It has been our experience that students are able to learn how to use most of these programs on their own and that use of these applications does not generally require a deep understanding of computation. In a phrase, we don’t teach them what they are going to learn by themselves anyway.

This course also does not delve very deep into the soft aspects of Computing. These topics are covered in a companion course (CS33b: Internet and Society), which is focused primarily on the social, ethical, legal, economic, political and aesthetic aspects of computers. It is our opinion that these issues are best taught in an interdisciplinary context. Indeed, the CS33b course is currently taught by a dozen instructors from half a dozen different departments.

The course does not teach algorithms and data structures. Although the students do learn to trace through the execution of fast-exponential procedures, gcd calculators, and the "map" function, we do not teach them to use computers for problem solving. Thus we do not ask them to write sorting procedures or programs to find average grade scores, etc.

We **do** teach "reactive" programming in this course, i.e. programs that interact with the user (through GUIs or HTML forms) and use the user-supplied information to generate responses and perform simple actions (logging, sending email, updating counters, performing simple calculations and tests). We also teach the students to understand how to trace recursive programs which is a far easier task than learning how to write recursive programs. More precisely, the students are required to be able to write applets and servlets in three languages (HTML, CSS, Scheme) and to trace programs in two additional "languages" (pcode assembly language, and CMOS circuit diagrams).

The goal in teaching them to write "reactive" programs and to trace recursive programs is to help them understand the deeper issues of computation more clearly. For instance, one of the applet programs we present is a simple "Psychiatrist" simulator which they are encouraged to modify. This provides a context for a deeper discussion of artificial intelligence, ethics, and the Turing problem. For another example, when we discuss the substitution model of Scheme the students are required to trace recursive programs with function parameters (e.g. map). This paves the way for a discussion of the Halting problem. We consider the consequences of extending the Scheme language by adding a primitive procedure (`halts? F X`) which returns true if (`F X`) eventually returns an answer and false if it throws an exception or does not return. In particular, we look at the following program:

```
(define (skeptical Q)
  (if (halts? Q Q) (skeptical Q) 'ha))
(skeptical skeptical)
```

The trace of (`skeptical skeptical`) yields the expected contradiction which then leads to a discussion of the limits of computation. It is true that the `skeptical` example only makes sense in the context of a Scheme which provides source code access to all procedures and closures, but the impossibility of adding a recursive "halts?" procedure still illustrates well the limits of computation.

We usually couple this lecture with a classroom exercise in which the students must prove that the instructor can not tell the future. The proof consists of asking the instructor to predict the student's behavior using the same strategy as the "skeptical" procedure.

A rough outline of the syllabus, which shows the context of the web-programming part of the course is shown below.

- 1 week **HTTP** and the structure of the Internet: IP addresses, ports, sockets, services, routers, gateways. Use of telnet, dig, traceroute, ping, portscan to illustrate these issues.
- 2 weeks **HTML/CSS** – the thirty non-style HTML tags and 10 basic CSS properties. Copyright issues.
- 3 weeks **Scheme Servlets** – quasi-string notation, abstraction, conditional execution, lists, file I/O, email, database access. Security, privacy, cookies, ethics.
- 3 weeks **Scheme Applets/Groupware** – GUI components, layout, callbacks, animation, networking primitives, groupware components. Doctor applet, Turing Test. Halting problem. Substitution model. Software licenses.
- 1 week **Assembly Language/Pcode** - von Neumann architecture, memory-mapped peripherals, memory, speed, bandwidth, cacheing, super-scalar architectures. Operating Systems, file systems, time sharing, ...
- 1 week **CMOS/Logic Circuits** - semiconductors (P/N-type), gates, circuits, adders, latches and bits.

Observe that the course contains a significant amount of non-Scheme material that would be found in most typical Computer Literacy courses (such as copyright issues and ethical questions dealing with servers), but with this programming-based approach these issues are more meaningful as the students are able to write servers that create logs and must deal with the resulting ethical questions.

## 4 Infrastructure

The students attend three (fifty minute) lectures each week and may optionally seek one-on-one help from class TAs if needed. The classes meet in a large lecture hall (300 seats) with a 10'x20' computer projection screen.

Almost all students have their own computers with a high speed access to the campus network, but they also

have access to public computer clusters of machines running Windows, MacOS, and Linux operating systems.

The class employs 1 TA for every 20 students. The TAs are each responsible for staffing the computer lab for three hours each week. The TAs are recruited from the A+ students of previous years with special attention to providing TA staff whose diversity in major, gender, race, and other factors matches that of the class.

Each student has an assigned TA who grades all of the homework projects, but a student may ask any TA for help with their homework. There is a 20 minute quiz each week (involving programming) which is graded by the instructor and all TAs in a 1-2 hour session. The instructor grades the final exam.

## 5 Courseware

The main language used in the course is Jscheme<sup>1</sup> [2, 3, 7], an open source implementation of Scheme in Java. It is almost completely compliant with the R4RS standard<sup>2</sup> [4] and also provides full access to Java using the Java Reflector syntax shown in Figure 1. Jscheme also provides full access to Java thread and exception handling.

The course uses a small but powerful subset of Scheme and also relies on a few selected Java reflectors and a small GUI-building library. For control flow and abstraction it uses `define`, `set!`, `lambda`, `if`, `cond`, `case`, `let*`. For primitives, it uses arithmetic operators and comparisons, a simple GUI-building library (providing declarative access to Swing components, events, and layout managers).

One fundamental problem with teaching a course in which students will be asked to write servlets is providing access to a machine that has that capability. We have developed a simple Jscheme webapp which plugs into the open source Jakarta Tomcat web server<sup>3</sup> and allows students to edit and upload their files to this common server directly from their browser. After registering for the course, the students visit the page on the server they want to edit or create and add a U to the end of the name. The server then generates a form that allows them to either upload the file or edit it in a textarea input form. If they supply the correct password, the file will be uploaded to the server. The advantage of this approach is that it gives them full access to their directory (including making subdirectories), and it requires no tools other than a web browser.

Although the instructor (or the System Administrator) must install and maintain this webserver, the students

<sup>1</sup><http://jscheme.sourceforge.net>

<sup>2</sup>strings are not mutable, and call/cc is only implemented for try/catch like applications

<sup>3</sup><http://jakarta.apache.org/tomcat/index.html>

do not need to download or install any software beyond the standard browsers (Netscape or Internet Explorer). If they are interested they can download and install their own personal webserver, but we currently do not require that.

Another useful tool, which was developed for this course, is the TATool [8]. This is a groupware application, written in Jscheme and delivered as a Java Web Start application or as a jar file. It provides a simple IDE for scheme development as well as providing FTP-like services to the course web server. In addition it allows students to connect with Teaching Assistants using a IM-like buddylist mechanism. The TAs can then view the student's program (but not edit it) and both students and TAs can comment on the program line by line in adjacent textareas. A shared whiteboard and a standard chatroom are also provided. The TATool allows each TA to connect to many students (using a tabbed pane with a separate tab for each student). Each student can also connect to many TAs (again using the tabbed pane model). Students can ask each other for help if no TAs are available. This tool has only been available as an early prototype in the recent CS2a course, but will be fully deployed starting in Summer 2002. It does require that Java Web Start be downloaded<sup>4</sup> and installed, but students are not required to use it.

## 6 Scheme Programming Concepts

The course spends six weeks covering Scheme Servlets and Scheme Applets. In the past we have covered servlets before applets, but one can reverse the order as the domains are quite different. In this section we provide an overview of the main concepts that they learn.

### 6.1 Scheme Servlets

Files which appear in the Jscheme webserver student directory with the extension ".servlet" are treated as Jscheme expressions which are evaluated to generate the html to send back to the client. After working with this model for a while, we found that the need to combine scheme and text resulted in programs containing large numbers of string-append's and quoted strings (with many quoted quotes). In response to this somewhat confusing syntax, we introduced a slight syntactic extension to Scheme which allows curly braces {} to be used in place of double quotes for strings. Moreover, inside a {} string, any scheme expressions appearing within square brackets [], are evaluated and appended into the string. These two devices make use of the unassigned outfix operators [] and {}, and allow for a more concise method for constructing strings in Scheme. We call this quasi-string notation<sup>5</sup>

<sup>4</sup><http://java.sun.com/products/javawebstart>

<sup>5</sup>The quasi-string notation is a syntactic variant on Bruce R Lewis' Beautiful Report Language (BRL) Syntax. Our approach

SYNTACTIC CONSTRUCT	JAVA MEMBER	EXAMPLE
"." at the end	constructor	(Font. NAME STYLE SIZE)
"." at the beginning	instance method	(.setFont COMP FONT)
"." at beginning, "\$" at end	instance field	(.first\$ '(1 2))
"." only in the middle	static method	(Math.round 123.456)
".class" suffix	Java class	Font.class
"\$" at end, no "." at beg.	static field	Font.BOLD\$
"\$" in the middle	inner class	java.awt.geom.Point2D\$Double.class
"\$" at the beginning	packageless class	\$ParseDemo.class

Figure 1: Java reflectors in Jscheme

For example, using quasi-string notation we can write

```
(define (captioned-image C I)
  {<table border=5>
    <tr><td>
      
    </td></tr>
    <tr><td>[C]
    </td></tr> </table>}}
```

which is equivalent to the following (less elegant) standard Scheme expression:

```
(define (captioned-image C I)
  (string-append
    "<table border=5>
    <tr><td>
      <img src=\"\" I \"\" alt=\"\" C \"\">
    </td></tr>
    <tr><td>\" C \"
    </td></tr> </table>"))
```

The quasi-string notation is similar to the quasiquote syntax used to construct s-expressions in Scheme.

### 6.1.1 Dynamic content

The first non-trivial examples of servlets that we provide are servlets that include runtime generated data (such as the current date, or information from the HTML headers, like the client operating system). For example, by enclosing their HTML in curly braces, changing the extension from html to servlet, they can add this dynamic content to their page just by including the [(java.util.Date.)] expression into their HTML.

```
{<html>
  <head><title>Date/Time</title></head>
  <body>
```

is based on the quasiquote/unquote approach for constructing lists in Scheme.

```
Current local time is
  [(java.util.Date.)]
</body>
</html>}
```

Evaluating this expression yields

```
<html>
  <head><title>Date/Time</title></head>
  <body>
    Current local time is
    Fri Sep 07 09:33:30 EDT 2001
  </body>
</html>
```

These small syntactic changes provide a gentle introduction to servlets that, as we will show below, leads naturally to abstraction, conditional execution, and expression evaluation.

Scheme servlets interact with the Tomcat environment through three Java servlet variables: **request**, **response**, **httpservlet**, (which are allowed to appear free in the quasi-string code). The **request** variable is used to get the HTTP headers. For example, to get the client's operating system type (from the header) we can use

```
[(.getHeader request "UA-OS")]
```

The **response** variable is used to set the MIME type (e.g. to return **text/plain** instead of HTML and to redirect the page, We can set MIME-type to an image type and redirect to an image as follows:

```
(.setContentType response "image/gif")
(.sendRedirect response "images/picture.gif")
```

The **httpservlet** variable can be used to get information about the scheme servlet (this is not often used by students, but is useful for experts).

## 6.1.2 Introducing Abstraction

Once the idea of dynamic content is clearly established, we move on to abstraction and show how to use the "define" form to create "scheme tags." This simple and powerful idea only requires an understanding of the substitution model of scheme evaluation, and yet allows students to start writing and sharing new HTML tag libraries, written in Scheme. For example, Figure 2 shows a typical and simple library that includes a generic webpage procedure and a captioned image procedure.

```
;; mylib.scm
(define (captioned-image C I)
  {<table border=5>
    <tr><td>
      
    </td></tr>
    <tr><td>[C]
  </td></tr> </table>})

(define (generic-page Title CSS Body)
  {<html>
    <head><title> [Title]</title>
    <style type="text/css" media="screen">
      <!-- [CSS] --></style></head>
    <body> [Body]</body>
  </html>})
```

Figure 2: An HTML abstraction library

An example of the use of this simple library is shown in Figure 3. The benefits of this sort of abstraction become even greater when the abstractions start using sophisticated inline-CSS style attributes to create a highly stylized HTML components.

```
(begin
  (load "webapps/user/tim/mylib.scm")
  (generic-page
    "Demo page for Scheme2002 talk"

    "body {background:black;color:white}
    h1{border: thick solid red}"

    {<h1>My Pets</h1>
      [(captioned-image
        "Snappy and Pepper" "cats.jpg")]
      <br>
      [(captioned-image
        "Missy" "missy.jpg")]
    })
```

Figure 3: Using HTML abstraction libraries

This technique for abstracting HTML is well-known in Lisp/Scheme web programming (e.g. LAML[9], BRL<sup>6</sup>) and is similar to Server-Side Includes in JSP<sup>7</sup> or the

<sup>6</sup><http://brl.sourceforge.net>

<sup>7</sup><http://java.sun.com/products/jsp>

publishing model of the Zope environment<sup>8</sup>.

## 6.1.3 Introducing User Interaction

The next pedagogical step is to introduce the notion of using HTML forms to send data from the user to the servlet.

To simplify the computational model for novice students, Jscheme provides easy access to form parameters using the (servlet (p1 p2 ...) ...) macro which binds the variables p1,... to the strings associated with the form parameters of the same names. This allows one to easily write servlets that process form data from webpages. This also proves to be a good time to introduce the notion of conditional execution (using if, cond, and case):

```
(servlet (password bg fg words)
  (load "webapps/user/tim/mylib.scm")
  (case password
    ((#null) ; first visit to page, make form
      (generic-page {color viewer form} { }
        {<h1>pw-protected color viewer</h1>
          <form method=post action="demo1.servlet">
            pw <input type=text name="pw"><p>
            bg <input type=text name="bg"><p>
            fg <input type=text name="fg"><p>
            text<textarea name="words">
            Enter text to view here</textarea>
            <input type=submit>
          </form>}))
    ("cool!") ; correct pw, process data
      (generic-page "color viewer"
        "body {background:[bg];color:[fg]}"
        words))
    (else ; incorrect password, complain!
      (generic-page "ERROR"
        " body {color:red;background:black}"
        {<h1>WRONG PASSWORD</h1>
          Go back and try again!}))))
```

Figure 4: A password protected page

For example, after a week of HTML instruction we have found that beginning students easily create HTML forms and it is then a small step to the servlet in Figure 4 which either generates a form or generates a response to the form, depending on whether the form parameter has been given a value by the browser.

<sup>8</sup><http://www.zope.org>

### 6.1.4 Expression Evaluation

The next step is to introduce numerical computation into servlets. An example, of the type of program the students are able to construct at this level is shown in Figure 5 below.

```
(servlet (inches pounds)
  (load "webapps/user/tim/mylib.scm")
  (if (equal? inches #null)
    ;; first visit to page, create form
    (generic-page {color viewer form} {})
    {<h1>BMI Calculator</h1>
     <form method=post action="bmi.servlet">
       height:
       <input type=text name="inches"> inches<br>
       weight:
       <input type=text name="weight">pounds<br>
       <input type=submit>
     </form>})
    ;; else compute BMI, display results
    (let* ( (h (Double. inches))
           (w (Double. pounds))
           (h-in-m (* h 0.0254))
           (w-in-kg (/ w 2.2))
           (bmi (/ w-in-kg (* h-in-m h-in-m))))
      (generic-page "Body Mass Index"
        " body {background:rgb(255,235,215)}"
        {<h1>Body Mass Index</h1>
         With a height of [inches] inches and
         a weight of [pounds] pounds, your
         Body Mass Index is [bmi] <br>
         Note: a BMI over 25 indicates you may be
         overweight, while a BMI over 30 indicates
         that your weight may cause significant health
         problems!}))))))
```

Figure 5: A sample quasi-string servlet

This requires three new ideas:

- data types (converting strings into numbers using `Double.`)
- evaluation of arithmetic s-expressions
- introduction of intermediate variables using `let*`

This is admittedly a big step. At this point we review the substitution model to explain how expression evaluation proceeds, and we introduce an environment model to explain the semantics of the `let*` expression.

For students to be able to write this type of servlet they need to learn to use prefix Scheme arithmetic expressions and to use the `servlet` and `case` macros.

### 6.1.5 System Interaction

We have also added a few additional primitives for writing or appending scheme terms to a file, and for reading a file either as a string or as a list of scheme terms. These allow students to easily write logs and counters as in Figure 6. This example also shows the `send-mail` procedure which allows the students to specify the "from", "to", "subject" fields and give a quasi-string for the body.

```
(servlet()
  (load "webapps/scheme/lib/cs2a.scm")
  (let* ((c (read-from-file "counter" 0))
        (d (list c (Date.)
                  (.getRemoteHost request))))
    (write-to-file "counter" (+ 1 c))
    (append-to-file "log" d)
    (send-mail
     "tjhickey@brandeis" "nobody@brandeis"
     "counter" {You got a hit: [d!]})
    {<html><body>
     This list has been visited by <xmp>
     [(read-string-from-file "log" "")]</xmp>
     and you are visitor number [(+ 1 c)]
```

Figure 6: Logs and Counters in test.servlet

In order to simplify the problem of associating log and counter files to servlets, these primitives read and write from files whose prefix is the name of the servlet. Thus, for the log and counters example, the "log" file would be named "test.servlet\_log" and the counter would be "test.servlet\_counter". The students can also use library procedures that allow absolute addresses for files, but this is discouraged.

### 6.1.6 Data Structures and map

Students naturally want to handle list-style data (e.g. multiple checkboxes in form data). This leads naturally into a description of "map" and also to table abstractions. We find it useful to introduce `map` before `car`, `cdr`, `cons`, since it provides a powerful and intuitively clear operation and does not require an understanding of recursion. Moreover, as the examples in Figure 7 below illustrate, the `map` procedure gives the students most of what they need to handle lists of data values. There is also a `map*` procedure which uses a generalized map that converts Java collection objects into lists, and hence can be used with arrays, hashables, etc.

## 6.2 Scheme Applets

After spending about three weeks studying servlets, we turn to client-side computing. The tomcat server has

```

(define (li x) {<li>[x]</li>})
(define (lis L) (map li L))
(define (ul L) {<ul>[(lis L)]</ul>})
(define (ol L) {<ol>[(lis L)]</ol>})
(define (td X) {<td>[X]</td>})
(define (tds Ts) (map tableitem Ts))
(define (tr Ts) {<tr> [(tds Ts)] </tr>})
(define (trs Rs) (map tr Rs))
(define (table Rs) {<table> [(trs Rs)] </table>})

```

Figure 7: Generating lists and tables

been configured so that any scheme program that ends with ".applet" is transformed into a Jscheme applet and runs on the client's browser. Likewise, Jscheme programs that end in ".snlp" are converted into Java Network Protocol format which will be automatically downloaded and run in the Java Web Start plugin.<sup>9</sup>

```

"John Doe"
"http://www.johndoe.com"
"years->secs calculator"
"Convert age in years to age in seconds"
"http://www.johndoe.com/jd.gif"

(jlib.JLIB.load)
(define t (maketagger))
(define w (window "years->secs"
  (menubar
    (menu "File"
      (menuitem "quit"
        (action (lambda(e) (.hide w))))))
    border
    (north (label "Years->Seconds Calculator"
      (HelveticaBold 60)))
    (center
      (table 3 2
        (label "Years:")
        (t "years" (textfield "" 20))

        (label "Seconds:")
        (t "secs" (label "")))

      (button "Compute" (action(lambda(e)
        (let*
          ((y (readexpr (t "years")))
            (s (* 365.25 24 60 60 y)))
            (writeexpr (t "secs") s))))))))))
(.pack w)
(.show w)

```

Figure 8: A sample SNLP program

Jscheme has also been extended to allow students to learn to implement simple programs with Graphical User Interfaces. We have written a library, JLIB, that provides declarative access to the AWT package (There is also a version for the Swing package). An example of a simple Scheme program using this library is shown be-

<sup>9</sup><http://java.sun.com/products/javawebstart>

low in Figure 8. The first five lines of the program listed above are strings that provide documentation about this program which is required by the Java Network Launching Protocol (JNLP).

### 6.2.1 JLIB

The JLIB model is based on five fundamental concepts:

- COMPONENTS – there are a small number of ways to construct basic components (buttons, windows, ...)
- LAYOUTS – there are a small number of ways to layout basic components (row, col, table, grid, ...)
- ACTIONS – there is a simple mechanisms for associating an action to a component
- PROPERTIES – there are easy ways for setting the font and color of components
- TAGS – this is a mechanism for giving names to components while they are being laid out.

Another key idea is that operations on all components should be as uniform as possible. For example, there are procedures "readstring" and "writestring" which allow one to read a "string" from a component, and write a string onto a component. Thus "writestring" can change the string on a label, a button, a textfield, a textarea. It can also change the title of a window or add an item to a choice component. Likewise, readstring returns the label of a button, the text in a textarea or textfield, the text of the currently selected item in a choice, the title of a window, and the text of a label. The readexpr and writeexpr procedures are similar, but they allow reading and writing of Scheme expressions on GUI components. For example, the following snippet of code defines a button which changes state when pushed:

```

(define (flip x)
  (case x
    (("on") "off")
    (("off") "on")))
(define B
  (button "off" (action (lambda(e)
    (writestring B (flip (readstring B)))))))

```

JLIB provides procedures for each of the main GUI widgets (window, button, menubar, label) and it also provides procedures for specifying layouts (e.g. border, center, row, col, table). The first few arguments of these procedures are mandatory (e.g. window must have a string argument, textfield requires a string and a integer number of columns). The remaining arguments are optional and can appear in any order. Examples are fonts, background colors, and actions.

The JLIB package provides a “tagger” procedure which allows one to give names to components *in situ*

- (define t (maketagger)) creates a tagger,
- (t NAME OBJ) assigns the NAME to the OBJ and
- (t NAME) looks up the OBJ with that NAME.

This makes the code more declarative because the name for a textfield appears with its constructor in the expression that creates the GUI.

## 6.2.2 Graphics and Animation

We also provide a simple graphics library providing access to a canvas with an offscreen buffer. The drawing primitives are the Java instance methods of the java.awt.Graphics class. The “canvas” procedure is a JLIB procedure that creates a canvas with an offscreen buffer accessed by (.bufferg\$ c) and which can be drawn to the screen using (.repaint c). The program in Figure 9 shows a simple example drawing a red ball moving across a blue background.

```
(jlib.JLIB.load)
(define c (canvas 400 400))
(define w (window "graphics1"
  (border
    (center c)
    (south
      (button "draw"
        (action (lambda(e)
          (run-it drawballs))))))))

(define (run-it F) (.start (Thread. F)))

(define (drawballs) (drawball 200))

(define (drawball N)
  (define g (.bufferg$ c)) ;get graphics object
  (.setColor g blue)
  (.fillRect g 0 0 1000 1000) ;; clear background
  (.setColor g red)
  (.fillOval g N N 100 100) ;draw red disk
  (.repaint c) ; copy buffer to screen
  (Thread.sleep 100L) ;; pause 0.1 sec
  (if (> N 0) (drawball (- N 1)) ;; loop
  )

(.resize w 400 400)
(.show w)
```

Figure 9: Graphics programming

The run-it procedure is used when the students write animations. They seem to understand the notion of

multi-threaded programming in the context of having several animations each running in their own thread <sup>10</sup>

## 6.3 Networking Abstractions

After spending two weeks mastering the JLIB library we introduce network programming using a simple model where applets communicate by sending scheme terms to each other through a **group-server**. Since applets are only able to open sockets on their host server, we must run the **group-server** on the same machine that manages the students’ applets. The students connect to this **group-server** using the **make-group-client** procedure:

```
(define S
  (make-group-client Name Group Host Port))
```

This creates an object, **S**, that can communicate with the group-server. To send the scheme terms **key b c ...** to the server, one evaluates the expression

```
(S 'send key b c ...)
```

The first term, **key**, is used as a filter. Indeed, the group-server bounces back every message it receives to all the members of the group. A member can specify how to handle a message using the **add-listener** method

```
(S 'add-listener key
  (lambda (key . restargs) ...))
```

This method indicates that the indicated procedure should be called on each message that arrives from the server with the specified key.

This model builds on the student’s experience with callbacks in GUI’s and with reading/writing on GUI components. The analogy is that “send” is like writing to a component and “add-listener” is like adding an action.

An example of the kind of applet that is explained in class is the chat applet shown in Figure 10. In the most recent semester we did not require students to write an applet using networked communication, but several students chose to write such applets for their final project. The best example was a pictictionary program which allowed any number of students to join in a game of pictictionary using a shared whiteboard as well as private and group chats. This program was written by a student with no previous programming experience and made use of almost all of the examples we had given previously in the course.

<sup>10</sup>We also have a version of run-it that looks for errors and reports them in a debugging window.

```

(jlib.JLIB.load)
(jlib.Networking.load)
(define (chatwin
  UserName ChatGroup Host Port)
  (define t (maketagger))
  (define S (make-group-client
    UserName ChatGroup Host Port))
  (define w (window "test"
    (col
      (button "quit" (action (lambda (e)
        (S 'logout) (.hide w))))
      (t "chatarea" (textarea 20 50))
      (t "chatline" (textfield "" 50
        (action (lambda(e)
          (S 'send "chat" (string-append
            UserName ": "
              (readstring (t "chatline"))))
            (writeexpr (t "chatline") ""))
          ))))))
      (S 'add-listener "chat" (lambda R
        (appendlnexpr (t "chatarea") R)))
      (.pack w) (.show w)
    w)
  (define (rand N)
    (Math.round (* N (Math.random))))
  (chatwin
    (string-append "user-" (rand 1000))
    "chat"
    (.getHost (.getDocumentBase thisApplet))
    23456)

```

Figure 10: A multi-room chat program

In the coming year we plan on introducing networked communication using the notion of groupware components. These are textareas and canvases which are shared among several users on the network. This approach may provide an even simpler model of network programming that builds more directly on their understanding of GUI programs.

## 7 Student Distribution

We have used Jscheme and its predecessors to teach a large Computer Literacy course (CS2a: Introduction to Computers) for the past five years. It is an elective class but is also one of several options for satisfying the science requirement. The class size has ranged in size from 144-260 students. The enrollments have risen and fallen in step with the strength of the computer-based economy, but have remained fairly high. The course is one of largest classes at Brandeis where there are only a handful (around 10-15) classes that have more than 100 students.

Class Size at end of course						
1997	1998	1999	2000	2001	2002	total
144	182	224	260	158	(55)	1023

The preenrollment for Autumn 2002 is 55 and will typically triple by the time the class begins.

The following tables show the results of a survey given to the largest class (Autumn 2000). The numbers sum to over 300 because the survey was given during the first week of class which is a shopping period when students are deciding which classes to take. Also note that students were encourage to specify their most likely first major even if they had not yet declared.

Distribution of Expected Majors						
Cosi	Science	Arts	Hum.	Soc-Sci	und.	Total
49	28	4	33	102	102	318

The course is most popular among freshman and sophomores, but it has substantial numbers of juniors and seniors as well.

freshman	sophomore	junior	senior
134	96	48	38

The following table gives a distribution of the students' self classification of their computer literacy. Although there are a few students that know how to program, the majority view themselves as having little or no computer experience:

none	novice	user	programmer	hacker
40	143	117	12	6

Most students have a computer in their room and have installed software on it, but a minority have created their own webpage:

have own computer?	can install software?	have own webpage?
290	235	84

Most students were PC users, but there were significant numbers of Mac and Linux users:

PC	Mac	Other
287	19	12

## 8 Outcomes

We have used several techniques to accommodate the non-science students that are a majority in this class. The homework assignments allow students to exercise their creativity in creating a web artifact (webpage,

servlet, applet, application) which must meet some general criteria. For example, in one assignment they are required to create a servlet that uses several specific form tags (in HTML) and generates a webpage in which some arithmetic computation is performed. This encourages a bricolage approach to learning programming concepts which seems to appeal to non-science majors.

The course features weekly quizzes which take an opposite approach. The students are shown a simple web artifact and asked to write the code for it during a twenty minute in-class quiz. This practice helps keep the students from falling behind in the class and also helps counterbalance the openness of the homework assignments.

The final exam is based on the weekly quizzes so the quizzes also prepare students for the exam. The course provides a high level of teaching assistant support and uses peers who have completed the course in a previous year. The students post their homework assignments on the web and are thereby able to learn from each other, while the creativity requirement and the sheer joy of creating keeps copying to a minimum.

In the most recent class the three hour open-notes final exam required students to write a webpage, a Scheme servlet, a Scheme applet, and to trace through Scheme code, a logic circuit, and a CMOS circuit. The goal of the exam was to test their ability to synthesize solutions to problems using the tools they had learned. A more detailed description of the exam is shown in Figure 11.

The exam was graded very strictly (but with partial credit given) and the grade distribution was unimodal and heavily skewed toward the high grades. The low grades were primarily from students with attendance problems.

<60	60-69	70-79	80-89	90-100
7	16	25	41	70
5%	10%	16%	26%	44%

The Homework grades were even more skewed as the expectation was that all students should be able to achieve perfect scores on the homeworks with sufficient support from the Teaching Assistants. The weekly quiz scores mirrored the final exam scores fairly closely.

## 8.1 Pitfalls

The course requires a substantial investment in TA resources and in class preparation time as there is no textbook for the course. Indeed the course has been heavily revised each year to include more web programming. We are currently working on a textbook which should lessen the class preparation time.

- Converting between hex, binary, decimal, and dotted decimal
- Writing the HTML/CSS for a webpage given its image under Netscape. This page contained forms (including a password field).
- Writing a servlet that processes the form data from the previous problem. The servlet had to verify that the password was correct (generating a complaint page if not). If the password was correct it had to initialize/increment a counter, send email containing the form data, and display an acknowledgement page with the counter data.
- Tracing Scheme processes (e.g. fibonacci-like procedures)
- Writing an applet to compute the number of months to repay a loan based on the principal, interest, and monthly payment. The applet had a specific layout they had to imitate and also had File and Help menus. They were given the infix version of the formula and an image
- Tracing a logic circuit (about the complexity of a two-bit adder)
- Trace a CMOS diagram (about the complexity of three argument and-gate).

Figure 11: Final Exam questions

The fact that the course is taught as a large lecture course makes it difficult to keep track of the students who are doing poorly. This is partly ameliorated by weekly quizzes which help track student performance. Smaller class sizes or sectionals might make it easier to track students, but would require a greater commitment of staffing resources.

The current version of software tools used in the course (debuggers, help systems, etc.) are not as well-suited for novice programmers as are other more mature systems (e.g. DrScheme), but they are available as applets so there is a tradeoff between ease of access and ease of use. We are strongly considering porting the class to DrScheme and/or other Scheme systems.

Although the course covers a great deal of material and requires the students to demonstrate their mastery of it in timed quizzes and exams as well as substantial homework projects, the grades are always highly skewed toward the top. This suggests that the class should be taught in two or more sections as the very best students are clearly not being sufficiently challenged. For these students a modified version of the course which included more "algorithmic" computer science would be ideal. This would, again, require a greater commitment of department resources to the non-major course offerings.

## 9 Lessons learned

Overall the most surprising aspect of the course is that these non-science students have been able to learn how to write servlets, applets, and applications in Scheme, all within a 6 week unit of a 13 week semester. Although they have not delved deeply into "algorithmic" computer science, most of the students do thoroughly understand the mechanism by which a computer program can specify the appearance and functionality of simple applets and servlets. They also understand the notion of a formal semantics (the substitution model) for a computer language and the idea of the evolution of a process as a model of computation as in SICP [1].

The primary reasons for the success of this approach seems to be two-fold:

- **Scheme reduces cognitive overload.** By using a subset of Scheme we eliminate the problem of learning complicated syntax (as one must only match parens (of various sorts) and quotes and the Jscheme IDEs help one do this) and also minimize the problem of learning the underlying abstract machine due to the declarative nature of the language. They can understand the Scheme programs they write using a combination of the substitution model with an intuitive notion of objects (window, buttons, label, menus), events (button pushes, choice selections), and simple operations on these objects (reading/writing data from GUI components or HTML fields). If we were to use Java for this class they would be exposed to a much more complicated model with different kinds of methods (static/instance/constructor), variables (static/instance fields, local variables, parameters), types (classes, interfaces, scalars), and a dizzying array of packages. The use of Jscheme reduces all of the Java libraries to a set of primitive procedures and greatly reduces cognitive overload.
- **JScheme makes applets and servlets easily accessible to non-majors.** By using a Scheme implemented in Java we are able to maintain strong student interest by embedding Scheme in applets, servlets, and JNLP applications and thereby allowing the students to develop web artifacts that are usually only accessible to upper level Computer Science majors. Most of these types of applications could be made accessible through other Scheme implementations. Applets would require a plug-in, but students would probably be just as excited (if not more excited) about creating double-clickable GUI applications in Scheme, which would not require a plug-in.

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