System Software

SYSTEM SOFTWARE: AN OVERVIEW
ASSEMBLERS AND ASSEMBLY LANGUAGE
OPERATING SYSTEMS
IMPLEMENTING SYSTEM SOFTWARE
System Software: An Overview

• “Naked” computer hard to deal with, e.g.,
  1. Write machine language program.
  2. Load program into memory starting at address 0.
  3. Load 0 into PC and start execution.

• Need virtual machine interface, which does the following:
  • Hides details of machine operation.
  • Does not require in-depth knowledge of machine internals.
  • Provides easy access to system resources.
  • Prevents accidental or intentional damage to hardware, programs, and data.

• Create virtual machine and associated interface with system software.
System Software: An Overview (Cont’d)

Figure 6.1 The Role of System Software
System Software: An Overview (Cont’d)

- System software provided by **Operating System (OS)**.
- Many types of system software in an OS, e.g.,
  - **Graphical User Interface (GUI)**: Access system services.
  - **Language services**: Allow programming in high-level languages, e.g., text editor, assembler, loader, compiler, debugger.
  - **Memory manager**: Allocate memory for programs and data and retrieve memory after use.
  - **Information manager**: Organize program and data files for easy access, e.g., folders, directories.
  - **I/O system manager**: Access I/O devices.
  - **Scheduler**: Manage multiple active programs.
System Software: An Overview (Cont’d)

Operating systems

Language services
- Interpreters
- Assemblers

Memory managers
- Compilers
- Loaders
- Garbage collectors
- Linkers

Information managers
- File systems
- Database systems

Scheduler

Utilities
- Text editors
- Graphics routines

Figure 6.2
Types of System Software
System Software: An Overview (Cont’d)

OS dramatically simplifies creation of software, e.g.,

1. Write source program $P$ in high-level programming language using a text editor.
2. Use an information manager to store $P$ as a file in a directory.
3. Use a compiler and an assembler to translate $P$ into an equivalent machine language program $M$.
4. Use scheduler to load, schedule, and run $M$ (with scheduler calling memory manager and loader).
5. Use I/O system manager to display output on screen.
6. If necessary, use debugger to isolate and text editor to correct program errors.
Assemblers and Assembly Language: Overview

- An assembly language is the human-friendly version of a machine language, courtesy of several features:
  - Symbolic op-codes, e.g., ADD, COMPARE;
  - Symbolic memory addresses and labels, e.g., IND, ONE, AFTERLOOP; and
  - Pseudo-ops which specify extra assembler directives, e.g., .DATA, .BEGIN, .END.

- An assembler converts an assembly language source program into a machine language object program; a loader then places the instructions in that object program in the specified memory addresses.
Assemblers and Assembly Language: Overview (Cont’d)

Figure 6.3
The Continuum of Programming Languages
Figure 6.4
The Translation/Loading/Execution Process (Assembly --> M.C.)
Assemblers and Assembly Language:  
An Example Assembly Language

<table>
<thead>
<tr>
<th>OC</th>
<th>Instruction</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>LOAD Lbl</td>
<td>( CON(Lbl) \rightarrow R )</td>
</tr>
<tr>
<td>1</td>
<td>STORE Lbl</td>
<td>( R \rightarrow CON(Lbl) )</td>
</tr>
<tr>
<td>2</td>
<td>CLEAR Lbl</td>
<td>( 0 \rightarrow CON(Lbl) )</td>
</tr>
<tr>
<td>3</td>
<td>ADD Lbl</td>
<td>( R + CON(Lbl) \rightarrow R )</td>
</tr>
<tr>
<td>4</td>
<td>INCREMENT Lbl</td>
<td>( CON(Lbl) + 1 \rightarrow CON(Lbl) )</td>
</tr>
<tr>
<td>5</td>
<td>SUBTRACT Lbl</td>
<td>( R - CON(Lbl) \rightarrow R )</td>
</tr>
<tr>
<td>6</td>
<td>DECREMENT Lbl</td>
<td>( CON(Lbl) - 1 \rightarrow CON(Lbl) )</td>
</tr>
<tr>
<td>7</td>
<td>COMPARE Lbl</td>
<td>if ( CON(Lbl) &gt; R ) then ( GT = 1 ) else 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>if ( CON(Lbl) = R ) then ( EQ = 1 ) else 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>if ( CON(Lbl) &lt; R ) then ( LT = 1 ) else 0</td>
</tr>
<tr>
<td>8</td>
<td>JUMP Lbl</td>
<td>( ADDR(Lbl) \rightarrow PC )</td>
</tr>
<tr>
<td>9</td>
<td>JUMPGT Lbl</td>
<td>if ( GT = 1 ) then ( ADDR(Lbl) \rightarrow PC )</td>
</tr>
</tbody>
</table>
### Assemblers and Assembly Language: An Example Assembly Language (Cont’d)

<table>
<thead>
<tr>
<th>OC</th>
<th>Instruction</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>JUMPEQ Lbl</td>
<td>if $EQ = 1$ then $ADDR(Lbl) \rightarrow PC$</td>
</tr>
<tr>
<td>11</td>
<td>JUMPLT Lbl</td>
<td>if $LT = 1$ then $ADDR(Lbl) \rightarrow PC$</td>
</tr>
<tr>
<td>12</td>
<td>JUMPNEQ Lbl</td>
<td>if $EQ = 0$ then $ADDR(Lbl) \rightarrow PC$</td>
</tr>
<tr>
<td>13</td>
<td>IN Lbl</td>
<td>Store input value at $ADDR(Lbl)$</td>
</tr>
<tr>
<td>14</td>
<td>OUT Lbl</td>
<td>Output $CON(Lbl)$</td>
</tr>
<tr>
<td>15</td>
<td>HALT</td>
<td>Stop program execution</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pseudo-op</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>.DATA Val</td>
<td>Create memory cell with value $Val$</td>
</tr>
<tr>
<td>.BEGIN</td>
<td>Begin program translation process</td>
</tr>
<tr>
<td>.END</td>
<td>End program translation process</td>
</tr>
</tbody>
</table>
Assemblers and Assembly Language: An Example Assembly Language (Cont’d)

• Access `.DATA`-created values with symbolic labels, e.g.,

```
NEGSEVEN:   .DATA -7
```

```
54: 10000111
```

\[
\text{NEGSEVEN} = 54
\]

• To prevent `.DATA`-created values from being interpreted as instructions, place all `.DATA` pseudo-ops after `HALT` at the end of the program.
Assemblers and Assembly Language: Example Assembly Language Code

```
set A to the value of $B + C$
LOAD B
ADD C
STORE A
...
A: .DATA 1
B: .DATA 2
C: .DATA 3
```
Assemblers and Assembly Language: Example Assembly Language Code (Cont’d)

if $A > B$ then
  set $C$ to the value of $A$
else
  set $C$ to the value of $B$

LOAD B
COMPARE A
JUMPGT IFPART
LOAD B
STORE C
JUMP ENDF

IFPART:
LOAD A
STORE C

ENDIF:

A:  .DATA 1
B:  .DATA 2
C:  .DATA 3
set \textit{IND} to 0
while \textit{IND} \leq \textit{MAXIND} do
\hspace{1em} \langle \textit{LOOPBODY} \rangle
set \textit{IND} to \textit{IND} + 1
\hspace{1em} \langle \textit{LOOPBODY} \rangle
CLEAR \textit{IND}
\textsc{LOOPSTART:}
\hspace{1em} \textsc{LOAD} \textit{MAXIND}
\hspace{1em} \textsc{COMPARE} \textit{IND}
\hspace{1em} \textsc{JUMPGT} \textsc{LOOPEND}
\textsc{INCREMENT} \textit{IND}
\textsc{JUMP} \textsc{LOOPSTART}
\textsc{LOOPEND:} \cdots
\cdots
\hspace{1em} \textsc{IND:.DATA 0}
\hspace{1em} \textsc{MAXIND:.DATA 25}
Assemblers and Assembly Language: An Assembly Language Program

Consider the following algorithm for computing and printing the sum of all values in a $-1$-terminated list:

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Set $SUM$ to 0</td>
</tr>
<tr>
<td>2.</td>
<td>Read the first list value into $CURVAL$</td>
</tr>
<tr>
<td>3.</td>
<td>while ($CURVAL \neq -1$) do</td>
</tr>
<tr>
<td>4.</td>
<td>Set $SUM$ to $SUM + CURVAL$</td>
</tr>
<tr>
<td>5.</td>
<td>Read the next list value into $CURVAL$</td>
</tr>
<tr>
<td>6.</td>
<td>Print the value of $SUM$</td>
</tr>
<tr>
<td>7.</td>
<td>Stop</td>
</tr>
</tbody>
</table>

Let’s implement this algorithm in assembly language.
Assemblers and Assembly Language:
An Assembly Language Program (Cont’d)

Step 1
SUM: .DATA 0
CURVAL: .DATA 0
ENDVAL: .DATA -1
.END

Step 2
.IN CURVAL

Step 3
LOOPSTART:
LOAD ENDVAL
COMPARE CURVAL
JUMPEQ LOOPEND

Step 4
LOAD SUM
ADD CURVAL
STORE SUM

Step 5
IN CURVAL
JUMP LOOPSTART

Step 6
LOOPEND:
OUT SUM

Step 7
HALT
Assemblers and Assembly Language: The Assembly Process

- Duties of the assembler:
  1. Translate symbolic op-codes into binary.
  2. Translate symbolic addresses and labels into binary.
  3. Execute all pseudo-ops.
  4. Place translation in object program file.

- As symbolic addresses and labels may be used before they are defined, translation done in two passes:
  
  **Pass 1**: Accumulate all symbolic label / binary address bindings in symbol table.
  **Pass 2**: Resolve all symbolic label references.

- Op-code / symbolic label lookup typically optimized by alphabetic op-code / label sorting and binary search.
Assemblers and Assembly Language: The Assembly Process (Cont’d)

**Figure 6.10** Generation of the Symbol Table

<table>
<thead>
<tr>
<th>Label</th>
<th>Code</th>
<th>Location Counter</th>
<th>Symbol Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOOP</td>
<td>IN X</td>
<td>0</td>
<td>Symbol</td>
</tr>
<tr>
<td></td>
<td>IN Y</td>
<td>1</td>
<td>Address</td>
</tr>
<tr>
<td></td>
<td>LOAD X</td>
<td>2</td>
<td>Value</td>
</tr>
<tr>
<td></td>
<td>COMPAR</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JUMPGT</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>DONE</td>
<td>OUT X</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>JUMP</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OUT Y</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>HALT</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>.DATA</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>.DATA</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Assemblers and Assembly Language: The Assembly Process (Cont’d)

<table>
<thead>
<tr>
<th>Instruction Format:</th>
<th>OP Code</th>
<th>Address</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 bits</td>
<td>12 bits</td>
</tr>
</tbody>
</table>

**Object Program:**

<table>
<thead>
<tr>
<th>Address</th>
<th>Machine Language Instruction</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>1101 00000000001001</td>
<td>IN X</td>
</tr>
<tr>
<td>0001</td>
<td>1101 00000000001010</td>
<td>IN Y</td>
</tr>
<tr>
<td>0010</td>
<td>0000 00000000001001</td>
<td>LOAD X</td>
</tr>
<tr>
<td>0011</td>
<td>0111 00000000001010</td>
<td>COMPARE Y</td>
</tr>
<tr>
<td>0100</td>
<td>1001 00000000000111</td>
<td>JUMPGT DONE</td>
</tr>
<tr>
<td>0101</td>
<td>1110 00000000001001</td>
<td>OUT X</td>
</tr>
<tr>
<td>0110</td>
<td>1000 00000000000000</td>
<td>JUMP LOOP</td>
</tr>
<tr>
<td>0111</td>
<td>1110 00000000001010</td>
<td>OUT Y</td>
</tr>
<tr>
<td>1000</td>
<td>1111 00000000000000</td>
<td>HALT</td>
</tr>
<tr>
<td>1001</td>
<td>0000 00000000000000</td>
<td>The constant 0</td>
</tr>
<tr>
<td>1010</td>
<td>0000 00000000000000</td>
<td>The constant 0</td>
</tr>
</tbody>
</table>

*Figure 6.13 Example of an Object Program*
Operating Systems

Major duties of an operating system:

- **User Interface**: Accept *system commands* from user and, if these commands are valid, schedule appropriate system software to execute command.

- **System Security and Protection**: Determine valid users and valid activities and accesses for users using usernames, passwords, and *access control lists*.

- **Efficient Management of Resources**: Optimize processor use by maintaining Running (active program), Ready (programs ready to execute), and Waiting (programs waiting on I/O requests) queues.

- **The Safe Use of Resources**: Prevent *deadlock* (two or more users have partial required resources) using resolution algorithms and protocols.
Implementing System Software: Compilers

• A compiler translates a program in a high-level programming language into a behaviorally equivalent program in a lower-level programming language.

• First compilers developed by Grace Hopper in early 1950s.

• Compilers can be cascaded, e.g., high-level language ⇒ medium-level language ⇒ assembly language ⇒ machine language.

Grace Hopper
(1906–1992)
Implementing System Software: Programming Languages

John Backus (1924–2007)

Grace Hopper teaching COBOL (early 1960’s)

- FORTRAN (FORmula TRANslation) created by Backus team at IBM in 1957; designed for scientific computation.
- COBOL (COrmon Business-Oriented Language) created by industry / government committee in 1959.
• BASIC (Beginner’s All-purpose Symbolic Instruction Code) created by Thomas Kurtz (1928–) and John Kemeney (1926-1992) at Dartmouth College in 1964.
• Designed as a programming language for everyone.
Implementing System Software: Operating Systems

• OS only possible after sufficient computer memory available for system software starting around 1955.

• Three OS generations to date:

     Run multiple programs in sequence with aid of Job Control Language (JCL).

     Run multiple programs in apparent parallel by swapping programs in and out of the control unit.


• Future OS will incorporate multimedia user interfaces (e.g., voice / gesture-based) and fully distributed execution.
Implementing System Software: User Interfaces

Doug Engelbart (1925-2013)

Engelbart and colleagues develop graphical user interface (GUI) and computer mouse at Stanford starting in 1963.
Implementing System Software: User Interfaces (Cont’d)

“The Mother of All Demos” (1968)
Implementing System Software: User Interfaces (Cont’d)

Xerox Alto (1973) [$25K (est)]

• Alto was first modern GUI-driven PC; also incorporated local-area networking and laserjet printers (WYSIWYG).

Xerox Star (1981) [$75K]

• Star intended for use in large corporations.
Implementing System Software: User Interfaces (Cont’d)

XEROX 8010 Star Information System

Star provides integrated text and graphics. A variety of type sizes and styles may be used.

<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pear</td>
<td>$0.20</td>
</tr>
<tr>
<td>Beans</td>
<td>$0.50</td>
</tr>
</tbody>
</table>

This is some text in a text frame.
Implementing System Software: User Interfaces (Cont’d)

- Starting in 1979, Steve Jobs re-creates GUI-based functionality at Apple in the Lisa and Macintosh PCs.
- Part of Macintosh application and OS development subcontracted to Microsoft starting in 1981.

Apple Macintosh (1984) [$2,500]
Implementing System Software: User Interfaces (Cont’d)

- Microsoft releases Windows v1.0 in 1985; legally emulated portions of Lisa and Mac look.
- Microsoft releases Windows v2.0 in late 1987; is not only much faster but (now illegally) identical to Mac look.
- By late 1980s, Windows has 90% market-share in GUI-based PC computing.
And If You Liked This . . .

- MUN Computer Science courses on this area:
  - COMP 2001: Object-oriented Programming and HCI
  - COMP 2003: Operating Systems
  - COMP 4712: Compiler Construction

- MUN Computer Science professors teaching courses / doing research in this area:
  - Ed Brown
  - Rod Byrne
  - Oscar Meruvia-Pastor