ECE 354 – Computer Systems Lab II

Compilation for PIC and DSPs

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Exam

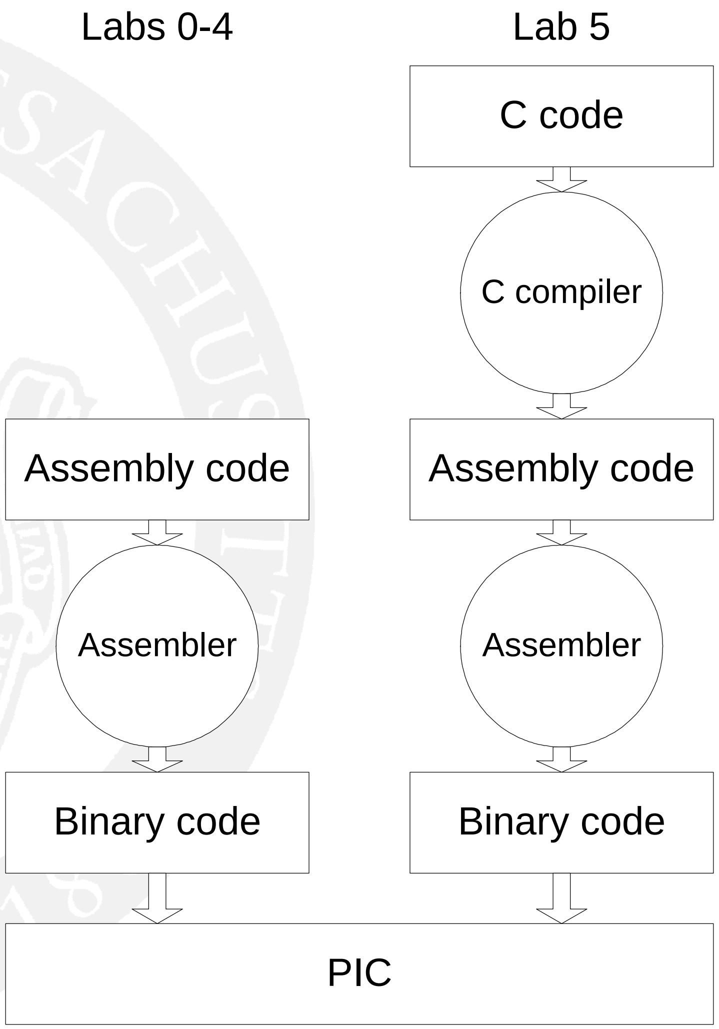
- Generally, it went well
  - Max 92, avg 72, min 41
- Grades are relative
- Solutions
  - Available in lab
- If you have any questions about the grading, see me.

Lab 5

- Lab 5 is an INDIVIDUAL PROJECT
- Lab 5 has two parts:
  - Compilation to PIC
  - Compilation to DSP
- All software lab, no hardware required
  - Return hardware Wednesday 5/5/04 2:30 in lab
- Demos due 5/13 and 5/14/04
  - Will keep 30 minute team sign-up slots
- Report due 5/17/04
  - Will be shorter report than for other labs

Compiling for the PIC

- Compilers convert "high-level" language to assembly code
  - Example: C/C++ compiler, Pascal compiler, …
- Assembly code is then assembled to binary code
  - Same as in lab 0-4
- What are the benefits / drawbacks for compiling?

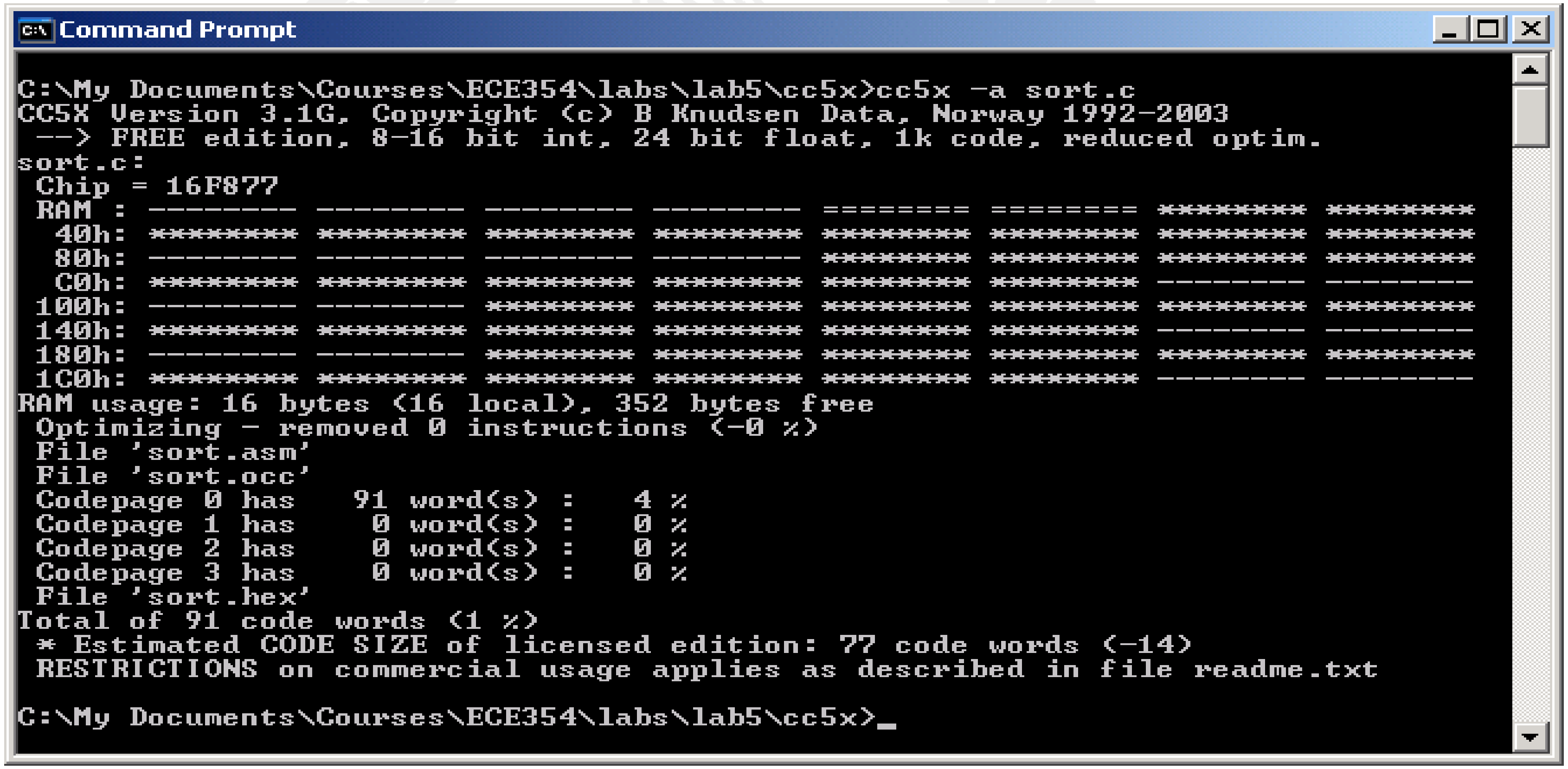


Compilers

- Benefits:
  - Easier to write programs
  - More likely to produce correct code
  - Can hide implementation details from user (e.g., memory banking)
  - Can do code optimization
- Drawbacks:
  - Possibly less efficient code
  - Difficult to match PIC components to programming abstractions
    - Timers, A/D, UART, etc.
  - Possibly cannot use all hardware component efficiently
  - Harder to debug

C Compiler for PIC

- We use free C-compiler:
  - http://www.bknd.com/cc5x/downl-stud.shtml
  - Limited functionality, for academic use only



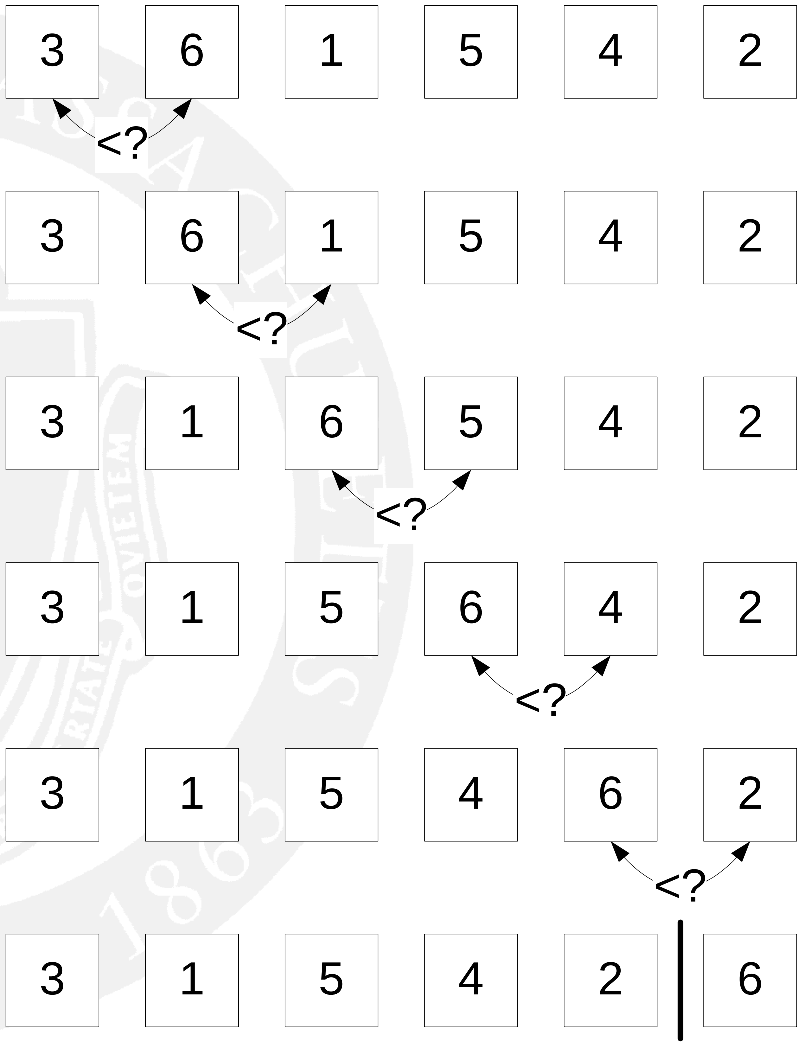
```
C:\My Documents\Courses\ECE354\labs\lab5\cc5x>cc5x -a sort.c
CC5X Version 3.1G, Copyright (c) B Knudsen Data, Norway 1992-2003
 --> FREE edition, 8-16 bit int, 24 bit float, 1k code, reduced optim.
sort.c:
 Chip = 16F877
 RAM : -------- -------- -------- -------- ======== ======== ******** ********
  40h: ******** ******** ******** ******** ******** ******** ******** ********
  80h: -------- -------- -------- -------- ******** ******** ******** ********
  C0h: ******** ******** ******** ******** ******** ******** -------- --------
 100h: -------- -------- ******** ******** ******** ******** ******** ********
 140h: ******** ******** ******** ******** ******** ******** -------- --------
 180h: -------- -------- ******** ******** ******** ******** ******** ********
 1C0h: ******** ******** ******** ******** ******** ******** -------- --------
RAM usage: 16 bytes (16 local), 352 bytes free
 Optimizing - removed 0 instructions (-0 %)
 File 'sort.asm'
 File 'sort.occ'
 Codepage 0 has   91 word(s) :   4 %
 Codepage 1 has    0 word(s) :   0 %
 Codepage 2 has    0 word(s) :   0 %
 Codepage 3 has    0 word(s) :   0 %
 File 'sort.hex'
Total of 91 code words (1 %)
 * Estimated CODE SIZE of licensed edition: 77 code words (-14)
 RESTRICTIONS on commercial usage applies as described in file readme.txt

C:\My Documents\Courses\ECE354\labs\lab5\cc5x>_
```

Lab 5 – Part I

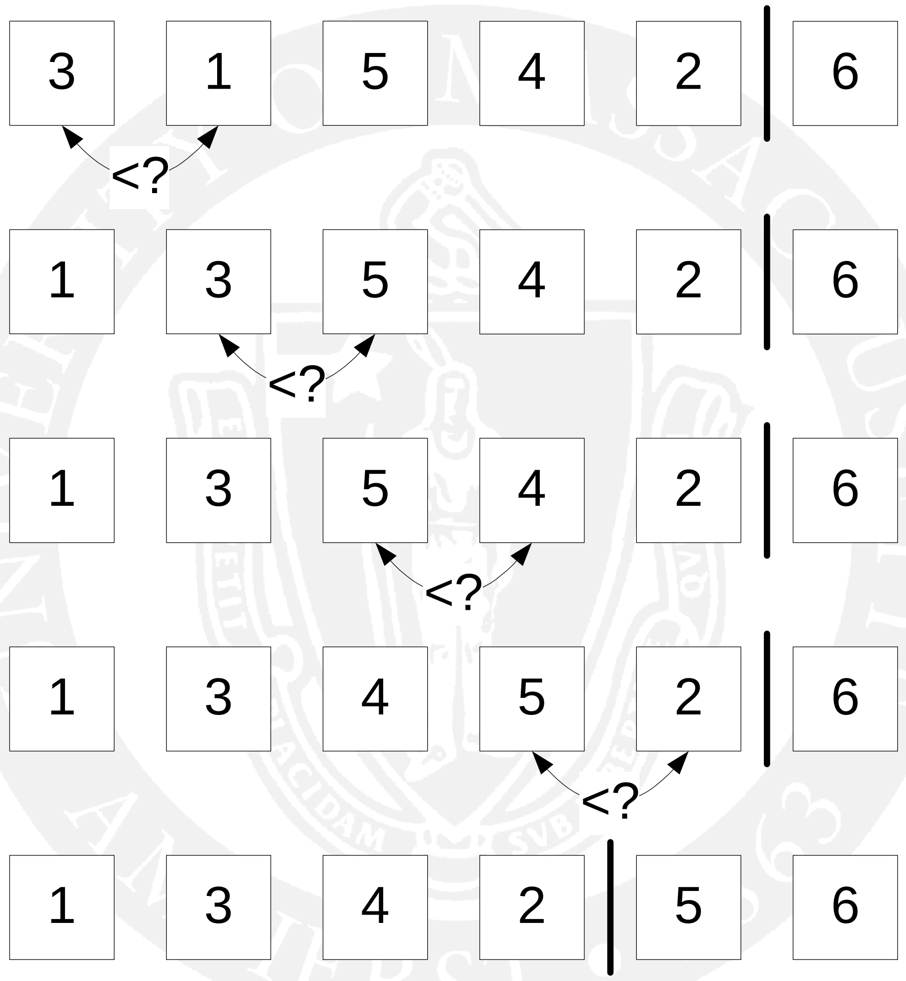
- Compare performance of compiled code vs. your assembly skills
  - Application: bubble-sort
- Measure time it takes to execute code
  - Compare compiled code vs. hand-coded assembly
- Time measurement on PIC:
  - Window -> Stopwatch
- Data is put in “by hand” in register file window

Bubble Sort (1)

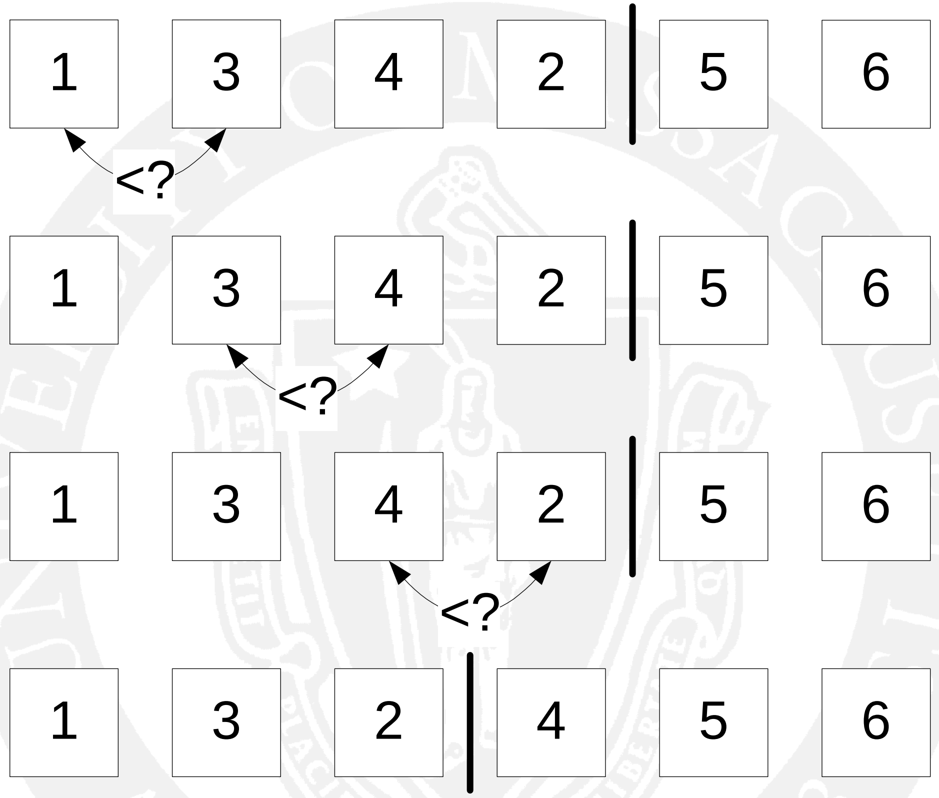
- Check neighboring pairs of elements for correct order
- If not ordered, swap
- Repeat until sorted
- Sequence of comparisons is important
- Largest values “bubble” to the top
  - Don’t need to be compared again



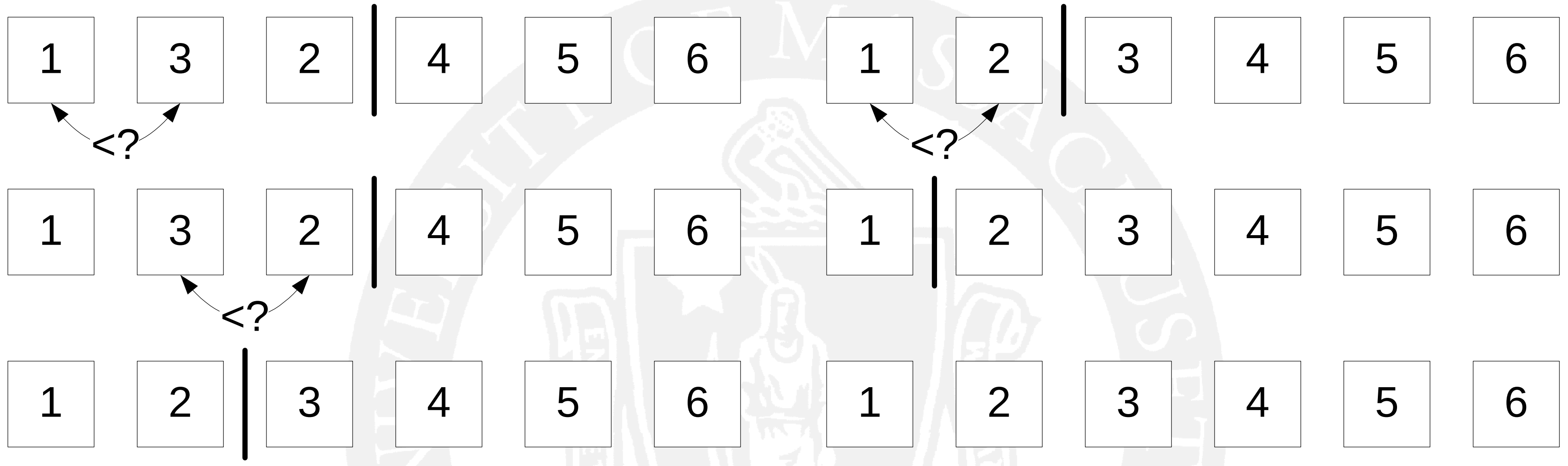
Bubble Sort (2)



Bubble Sort (3)

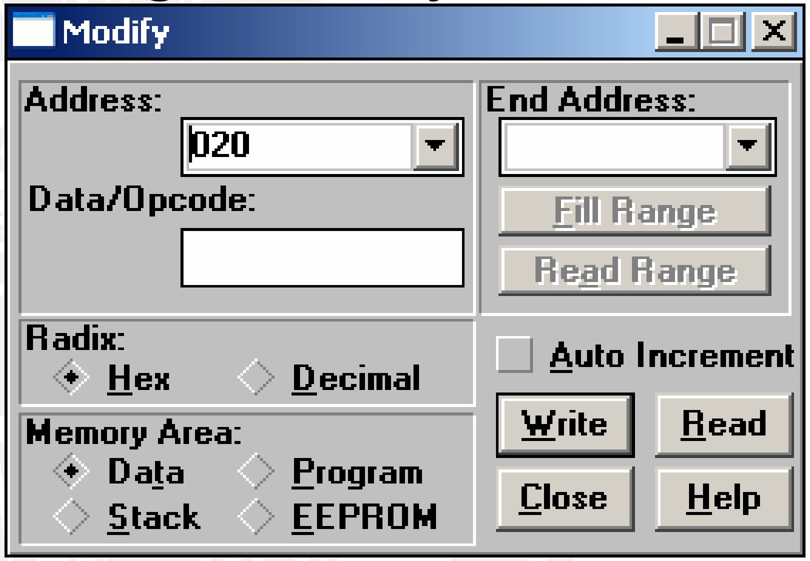


Bubble Sort (4)



Details

- Enter data to be sorted in registers "by hand"
  - Window -> Fill Registers
  - Right-click on data


Modify

Address: 020

End Address:

Data/Opcode:

Radix: [✓ Hex] Decimal

Memory Area: [✓ Data] Program Stack EEPROM

Auto Increment

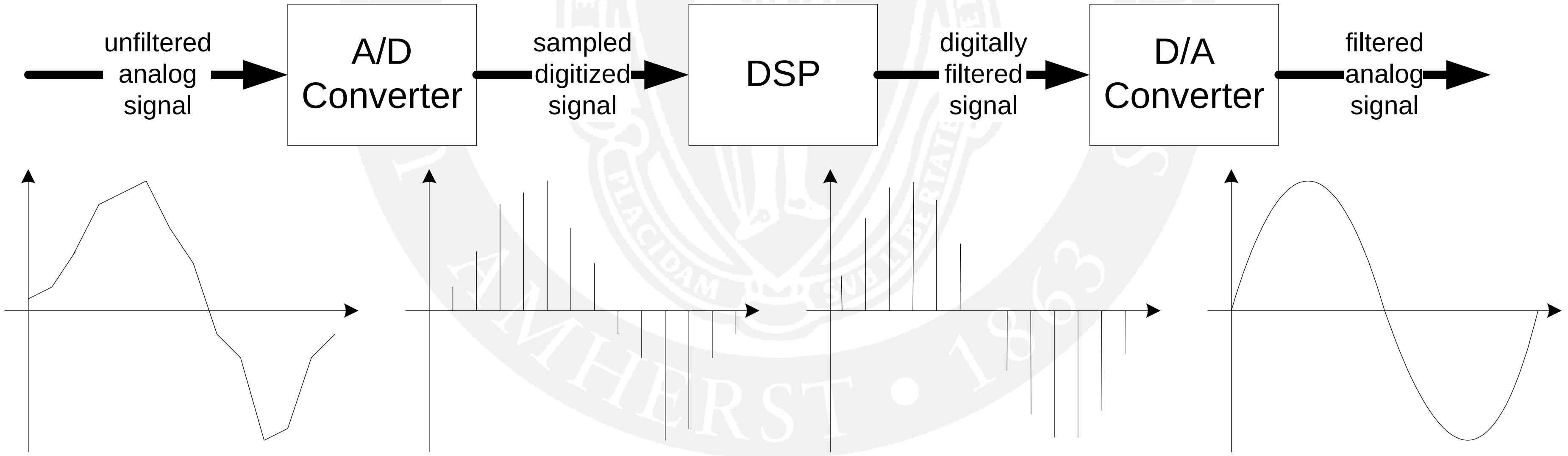
- Run on several different data sets
  - Different data will change results
  - Use worst-case and best-case as extremes
- Note results from different runs for lab report
  - Write down data and run-time

Lab 5 – Part II

- Digital Signal Processors (DSP)
  - Another type of embedded processor
  - Instead of controlling peripherals (PIC), a DSP processes signals
- Examples of DSP applications:
  - CD players
  - Mobile phones
  - Hard drive controllers
  - Communication equipment
  - Speech processing
- Why bother?
  - You should see another type of architecture in ECE 354
  - DSPs provide significantly more performance for certain apps
  - You might use a DSP in your senior design project

Example DSP Application

- Digital filtering of signals
  - Requires A/D and D/A converters
- Programmable for different purposes
- More precise than analog circuitry
  - Not temperature dependent
  - More accurate for low frequencies



DSP Filters (1)

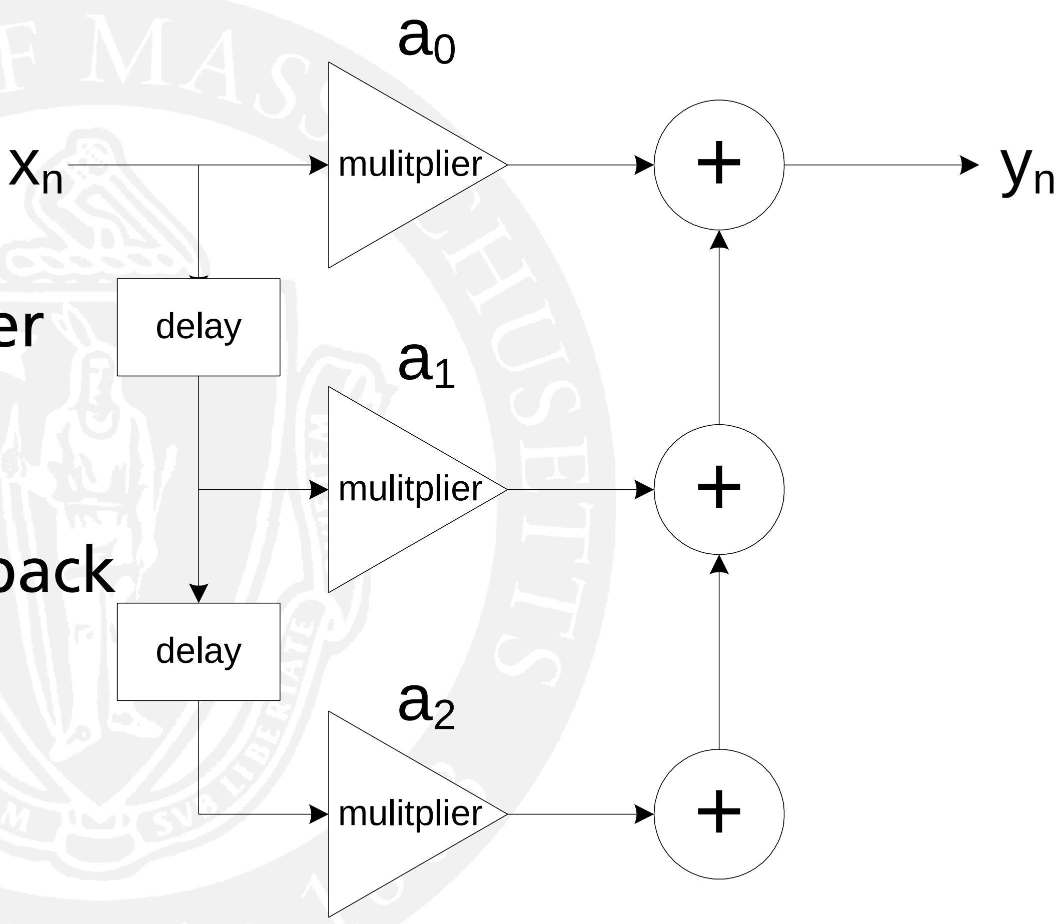
- Notation conventions
  - x_i are data points that are sampled by A/D converter
  - y_i are output values generated by DSP
  - n is current time
  - a are filter coefficients
- Example filters:
  - Simple gain filter: $y_n = K * x_n$
    - Depends only on current input value
  - Two-term average filter: $y_n = ½ * (x_n + x_{n-1})$
    - Depends on past input values
  - No dependency on output (Finite Impulse Response (FIR))

DSP Filters (2)

- Infinite Impulse Response (IIR) filter examples:
  - Dependency on past output: $y_n = x_n + y_{n-1}$
- "Order" of a filter:
  - Uses n past values, then nth order filter
  - Example: $y_n = ½ * (x_n + x_{n-1})$ is first order FIR filter
- General specification:
  - FIR: $y_n = a_0\, x_n + a_1\, x_{n-1} + a_2\, x_{n-2} + \ldots$
  - IIR: $y_n = (a_0 x_n + a_1 x_{n-1} - b_1 y_{n-1}) / b_0$
    or $b_0 y_n + b_1 y_{n-1} = a_0 x_n + a_1 x_{n-1}$
- "Multiply and accumulate" is fundamental operation of DSP

Multiply and Accumulate

- Basic architecture:
  - Requires delay element
  - Multipliers implement coefficients
- Example is second order FIR filter
  - Why?
- IIR filter requires feedback

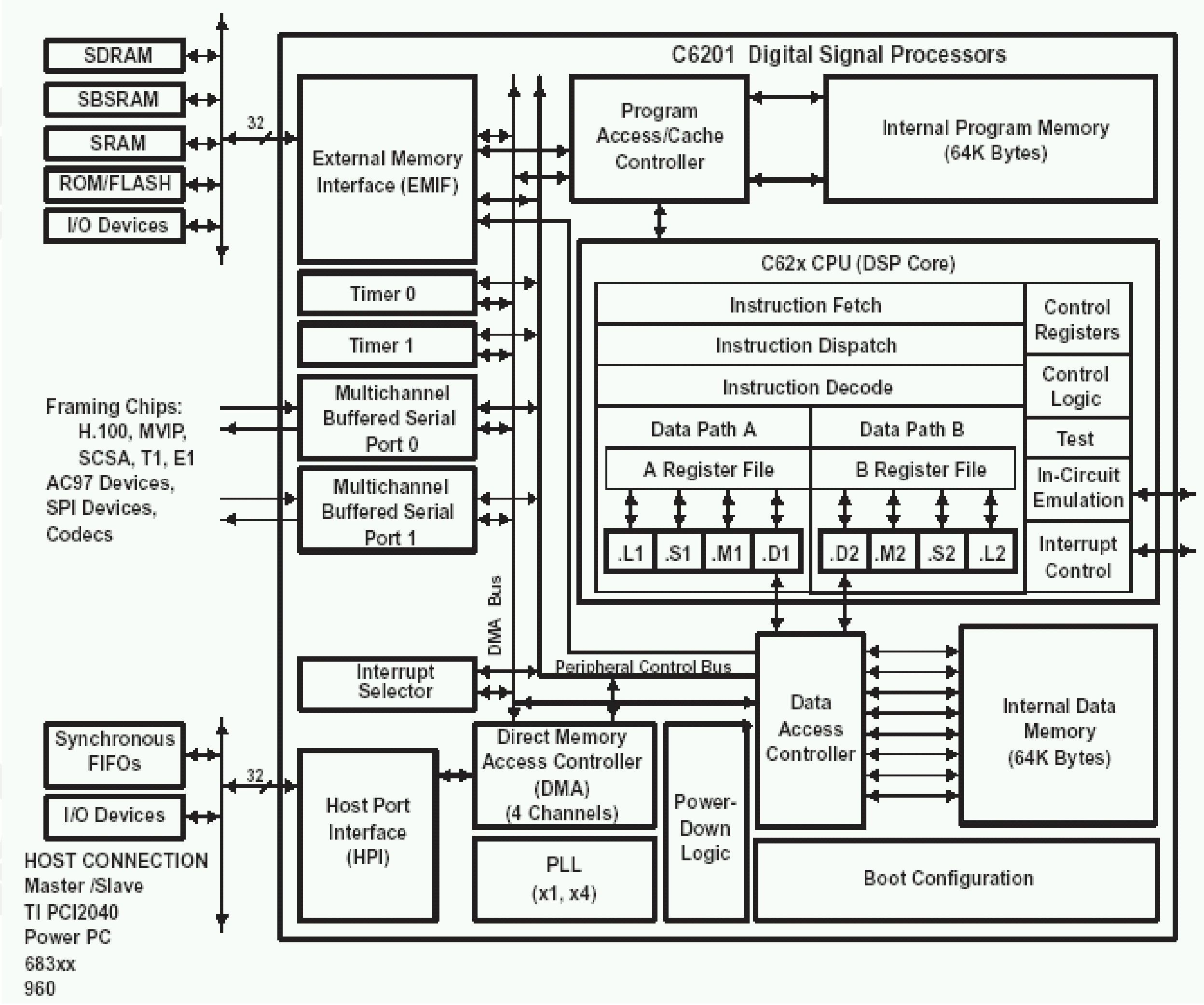


DSP Characteristics

- Typically for applications with high bandwidth and high computational requirements
- A/D and D/A converters
- Typically Harvard architecture
- Support floating or fixed point operations and multiplications
- Multiple ALU operations in same clock cycle
  - More parallelism gives more performance
- Multiple simultaneous memory accesses
- Structured to do multiply/accumulate operations
  - Necessary for filter operations

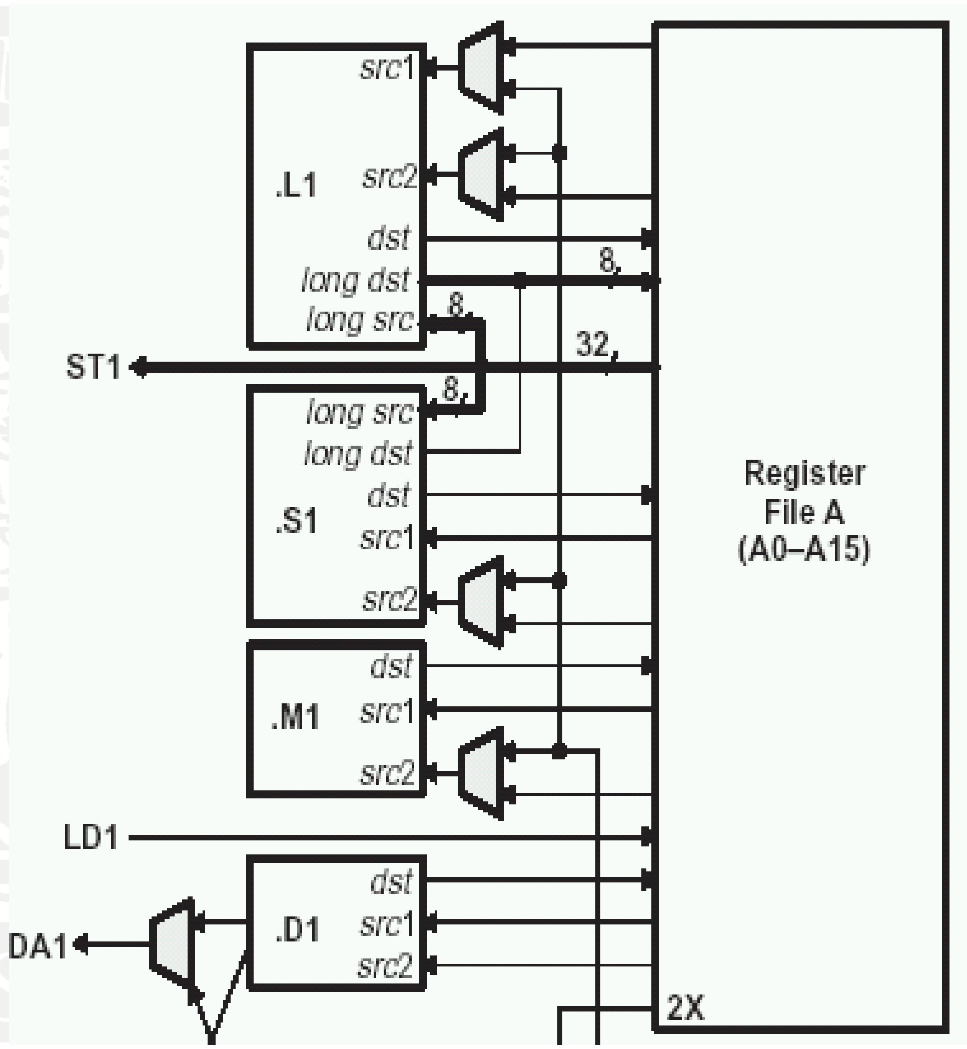
DSP Architecture

- Texas Instruments TMS3200C6201
- Similarities to PIC:
  - Harvard Arch.
  - Timers
  - Interrupts
  - ICD
- Differences to PIC:
  - Multiple data paths
  - External memory interface
  - …


SDRAM
SBSRAM
SRAM
ROM/FLASH
I/O Devices
32
C6201 Digital Signal Processors
External Memory Interface (EMIF)
Program Access/Cache Controller
Internal Program Memory (64K Bytes)
C62x CPU (DSP Core)
Instruction Fetch
Instruction Dispatch
Instruction Decode
Control Registers
Control Logic
Test
In-Circuit Emulation
Interrupt Control
Data Path A
Data Path B
A Register File
B Register File
.L1 .S1 .M1 .D1
.D2 .M2 .S2 .L2
Timer 0
Timer 1
Framing Chips: H.100, MVIP, SCSA, T1, E1
AC97 Devices, SPI Devices, Codecs
Multichannel Buffered Serial Port 0
Multichannel Buffered Serial Port 1
DMA Bus
Peripheral Control Bus
Interrupt Selector
Data Access Controller
Internal Data Memory (64K Bytes)
Synchronous FIFOs
I/O Devices
HOST CONNECTION Master /Slave TI PCI2040 Power PC 683xx 960
Host Port Interface (HPI)
Direct Memory Access Controller (DMA) (4 Channels)
PLL (x1, x4)
Power-Down Logic
Boot Configuration

DSP Data Path

- L1, S1: arithmetic, logic, branch instructions
- M1: multiplier
- D1: data transfer between register file and memory and transfer to other data path
- Same units on second data path
- All units can operate in parallel (VLIW)



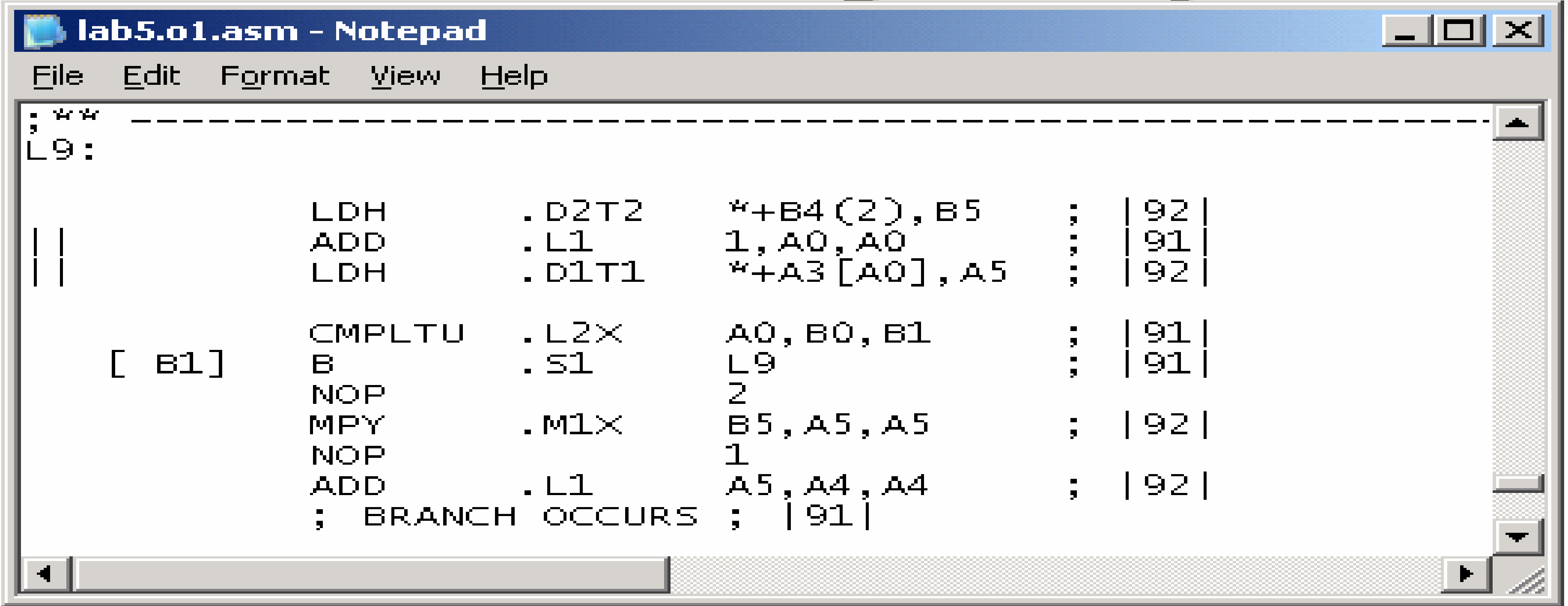
Programming DSPs

- VLIW (Very Large Instruction Word)
  - One "instruction" controls all eight data path units
- Hard to program by hand
  - User programs in C
  - Compiler figures out dependencies and some optimizations
  - User can optimize code by hand
- For real-time applications:
  - Repeated optimization, profiling, more optimizations, …
- Lab 5: compare performance of code with different levels of optimization
  - Application: dot product on vectors (multiply and accumulate)

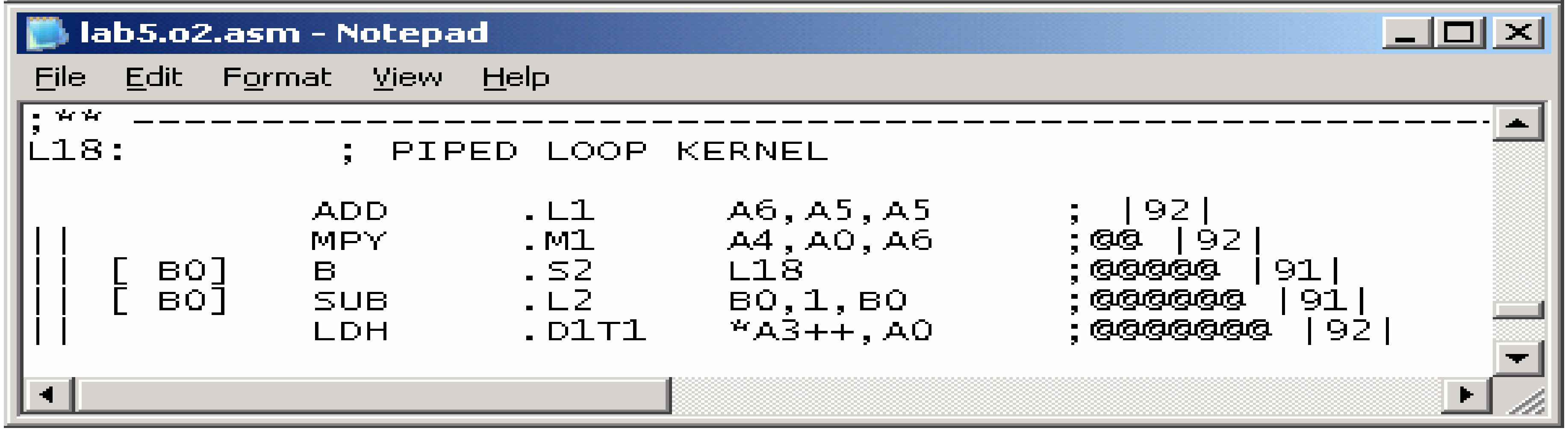
Lab 5 – DSP Part

- You are given C code that computes vector sum
- You need to add code that computes dot product
- Compile code and simulate
  - Program reports number of cycles used as output
  - Compile with different levels of optimization
- Compare DSP assembly code
  - Understand reasons for speedup
  - See how many parallel instructions can be issued
- What you will learn
  - More parallelism results in faster code
  - Optimization is important part of DSP programming

Lab 5 – Assembly Comparison



```
;** ---------------------------------------------------------------
L9:

           LDH     .D2T2    *+B4(2),B5    ;  |92|
||         ADD     .L1      1,A0,A0       ;  |91|
||         LDH     .D1T1    *+A3[A0],A5   ;  |92|

           CMPLTU  .L2X     A0,B0,B1      ;  |91|
   [ B1]   B       .S1      L9            ;  |91|
           NOP              2
           MPY     .M1X     B5,A5,A5      ;  |92|
           NOP              1
           ADD     .L1      A5,A4,A4      ;  |92|
           ; BRANCH OCCURS ;  |91|
```



```
;** ---------------------------------------------------------------
L18:         ; PIPED LOOP KERNEL

           ADD     .L1      A6,A5,A5      ;  |92|
||         MPY     .M1      A4,A0,A6      ;@@  |92|
|| [ B0]   B       .S2      L18           ;@@@@@  |91|
|| [ B0]   SUB     .L2      B0,1,B0       ;@@@@@@  |91|
||         LDH     .D1T1    *A3++,A0      ;@@@@@@@  |92|
```

Lab 5 Summary

- Part I: Bubble sort – C compiler vs. you
  - Write bubble sort in C and compile to assembly
  - Write bubble sort in assembly
  - Compare run-time performance for both
  - Perform 5 different measurements (data sets) for each
  - Show comparison
- Part II: DSP code optimization
  - Use code skeleton and at dot product for vectors
  - Compile with three different optimization levels
  - Simulate code and compare number of cycles spend
  - Look at generated assembly code and understand why
  - Optional: improve your code and reduce cycles
- Reminder: individual project – everyone has to do it…

Challenge

For both parts of the lab, a competition is held. For both competitions, the goal is to write the fastest code:

1. PIC code: write the **fastest bubble sort** that can sort the worst case data array.
2. DSP code: write the **fastest dot product** function.

The winner of each competition receives an **extra 10 points** for lab 5 (the total of lab 5 cannot exceed 100 points). If there are multiple competitors who achieve the best result, the 10 points will be divided between them (fractions of points are rounded off). If there is a single winner for the PIC competition, he or she may carry the title "**ECE354 Master Assembly Crafter**." If there is a single winner for the DSP competition, he or she may carry the title "**ECE354 Master Parallelism Exploiter**." If both competitions are won by the same individual, he or she may carry the title "**ECE354 Supreme Embedded Coder**." During lab hours, the current best performance should be announced on the blackboard in the lab. All competitors must have their solution's performance announced on the blackboard by Wednesday 5/12/04 to give others a chance to counter (updates due to code improvements are allowed and encouraged).

References

- Part I:
  - On course web page: link to C compiler, example C code
  - Bubble sort: read today’s slides or look on web
- Part II:
  - DSP Data Sheet and Programmer's Guide on course web page (recommended: Programmer’s Guide Chapter 2)

Miscellaneous

- Return of lab bench hardware and keys
  - Wednesday 2:30 in lab
    - One member of each group must be there
  - If you have broken components, please tell Keith – don't just put them back
- Course Evaluation
  - In just one minute…

The End…

- …almost
- I hope you enjoyed to course
- Hopefully you have learned about:
  - Programming PICs
  - Integrating PICs with other hardware
  - General system concepts: interrupts, timers, A/D conversion, buses, serial communication, etc.
  - Debugging your software and hardware
  - Teamwork
- There's a good chance you'll be able to apply your knowledge in the real world
  - SDP next semester
  - At your job