Outline

- Announcements:
  - HW II Idue Friday!
- Validating Model Problem
- Software performance
- Measuring performance
- Improving performance

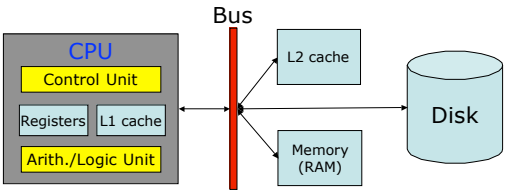
Validating Model Problem

- Our solution C is only an approximation of the true solution
- The accuracy of the approximation will depend on
  - dt
  - dx
  - "smoothness" of the initial conditions
- Two things to watch for:
  - lambda <1--solution will "blow up" if lambda>1
  - decreasing dx will make solutions more accurate
    - Try at coarse (m=10) and fine resolution (m=100)

Software Performance

- Factors influencing speed
  - Hardware
    - Clock speed, memory size/speed, bus speed
  - Algorithmic scaling
    - What happens as n gets big?
  - Interaction between algorithm and hardware
    - Compiler optimizations vs. hand tuning

Computer Architecture



- Von Neumann described a memory hierarchy
  - Fast----------> slow
  - $$$----------> cheap
  - Register L1 L2 RAM Disk

Architecture and Performance

- Avoid using the disk!
  - Minimize reading and writing
  - Buy more RAM so you don't use virtual memory
- Buy a system with lots of fast cache
- Buy a system with lots of RAM
- Then, if you have money left, buy a fast chip

Algorithm Performance

- There are often several algorithms for solving the same problem, each with its own performance characteristics
- Much of computer science is concerned with finding the fastest algorithm for a given problem
- Typically, we're interested in how an algorithm *scales*
  - How it performs as the problem size increases
  - To determine this, we need an accounting system (or model) of how a program runs
  - The simplest model assumes all commands take the same amount of time, so we just need to count commands
  - We could use more complicated models that weight commands

Algorithmic Performance of Linear Search

- Linear Search
  - Inputs=integer array x of length n, value k
  - Output: j s.t. x[j]==k, or j=-9 if k not in x

```
int LinSearch(int x[], int n, int k){
        j=0;
        while(x[j] != k & j<n){
                j=j+1;
        }
        if(j==n){
                return(-9);
        }else{
                return(j);
        }
}
```

Algorithmic Performance of Binary Search

- Binary Search
  - Inputs=SORTED integer array x of length n, value k, integers st >=0 and en<=n
  - Output: j s.t. x[j]==k, or j=-9 if k not in x[st:en]

```
int BinSearch(int x[], int st, int en, int k){
        int mid, ans;
         mid=(en-st)/2+mod(en-st,2); //middle of array
        if(vec[st+mid] == k){
                ans=st+mid;
        } else {
                if(mid<1){
                        ans=(-1);
                } else {
                        if(vec[st+mid] < k) {
                          ans=BinSearch(vec, (st+mid+1), en, k);//Search on right
                        } else {
                          ans=BinSearch(vec, st, (st+mid-1), k);//Search on left
        }}}
            return(ans);
        }
```

Comparing Linear and Binary Search

- Linear Search
  - max n iterations through loop
  - will work on any array
- Binary Search
  - max $\log_2(n)$ recursions ($\log_2(n)<n$)
  - faster if x is already sorted
  - but sorting takes approx. n^2 steps
- So, if you have to perform < n searches, use linear search
- If you have to perform >n searches, sort first, then use BinSearch

Interaction between algorithm and hardware

- There are several ways to implement the same algorithm
- Their performance could be very different, if they get compiled in different ways.
- The differences are due to interactions with the memory hierarchy

Rules of thumb

- Minimize computation (precomputing)

```
s=sqrt(b*b-2*a*c)
x1=(-b+s)/(2*a);x2=(-b-s)/(2*a);
```

  - better than

```
x1=(-b+ sqrt(b*b-2*a*c))/(2*a); etc.
```

- Minimize division

```
overdx2=1/dx;
overdx2=overdx2*overdx2;//1/dx^2
for(j=0;j<m;j++){sigma[j]=k[kJ][j]*dt*overdx2;}
```

- Minimize function/subroutine calls (inlining)
  - There is overhead associated with calling functions
  - This goes against good programming which encourages modularity

Rules of Thumb

- Avoid big jumps in memory
  - Data is moved from RAM to cache in chunks
  - Accessing arrays sequentially maximizes cache-reuse
  - Special implication for 2 (or higher) D arrays
    - Memory is sequential:

A00	A01	A02
A10	A11	A12

A00
A01
A02
A10
A11
A12

Row Major: C, C++, Java, Matlab

```
for(j=0;j<2;j++){
  for(k=0;k<3;k++){
    A[j][k]=…
  }
}
```

A00
A10
A01
A11
A02
A12

Column Major: FORTRAN

```
do k=1,3
 do j=1,2
    A(j,k)=…
 enddo
enddo
```

Improving performance

- To improve algorithmic performance
  - Take more CS!
- To improve interaction with hardware
  - Check out compiler optimizations
  - Then, start hand-tuning the code

Compiler Optimization

- A good compiler can take care of lots of things automatically
  - some precomputing
  - some inlining (for small functions)
  - other things like loop unrolling:

```
for(j=0;j<100;j++){
  for(k=0;k<20;k++){
    A[j][k]=…
  }
}
```

```
for(j=0;j<100;j++){
  for(k=0;k<20;k+=4){
    A[j][k]=…
    A[j][k+1]=…
    A[j][k+2]=…
    A[j][k+3]=…
  }
}
```

Measuring Performance

- Before we start messing with working code, we should identify where code is slow
- This is called profiling
  - Goal is to identify bottlenecks--places in the code that limit performance
- We can use profiling tools like prof (gprof) or insert timing calls
- Important to check performance on problems of different sizes

My Advice

- Before you do anything, make sure your code works
  - well-tuned incorrect code is still incorrect
  - It is better to solve your problem slowly than not at all!
- Look for algorithmic improvements
- Try compiler options
  - Read your compiler's manual to learn about what they do
- Last but not least, try hand tuning