Introduction To Computer Systems

15-213/18-243, Spring 2011

Recitation 7 (performance)

Monday, February 21

Agenda

- Performance review
  - Program optimization
  - Memory hierarchy and caches

Performance Review

- Program optimization
  - Efficient programs result from:
    - Good algorithms and data structures
    - Code that the compiler can effectively optimize and turn into efficient executable
  - The topic of program optimization relates to the second

Performance Review (cont)

- Modern compilers use sophisticated techniques to optimize programs
- However,
  - Their ability to understand code is limited
  - They are conservative
- Programmer can greatly influence compiler’s ability to optimize

Optimization Blockers

- Procedure calls
  - Compiler's ability to perform inter-procedural optimization is limited
  - Solution: replace call by procedure body
    - Can result in much faster programs
    - Inlining and macros can help preserve modularity
- Loop invariants
  - Expression that do not change in loop body
  - Solution: code motion

Optimization Blockers (cont)

- Memory aliasing
  - Accessing memory can have side effects difficult for the compiler to analyze (e.g., aliasing)
  - Solution: scalar replacement
    - Copy elements into temporary variables, operate, then store result back
    - Particularly important if memory references are in innermost loop

Loop Unrolling

- A technique for reducing loop overhead
  - Perform more data operations in single iteration
  - Resulting program has fewer iterations, which translates into fewer condition checks and jumps
  - Enables more aggressive scheduling of loops
  - However, too much unrolling can be bad
    - Results in larger code
    - Code may not fit in instruction cache

Other Techniques

- Out of order processing
- Branch prediction
- Less crucial in this class

Caches

- Definition
  - Memory with short access time
  - Used for storage of frequently or recently used instructions or data
- Performance metrics
  - Hit rate
  - Miss rate (commonly used)
  - Miss penalty

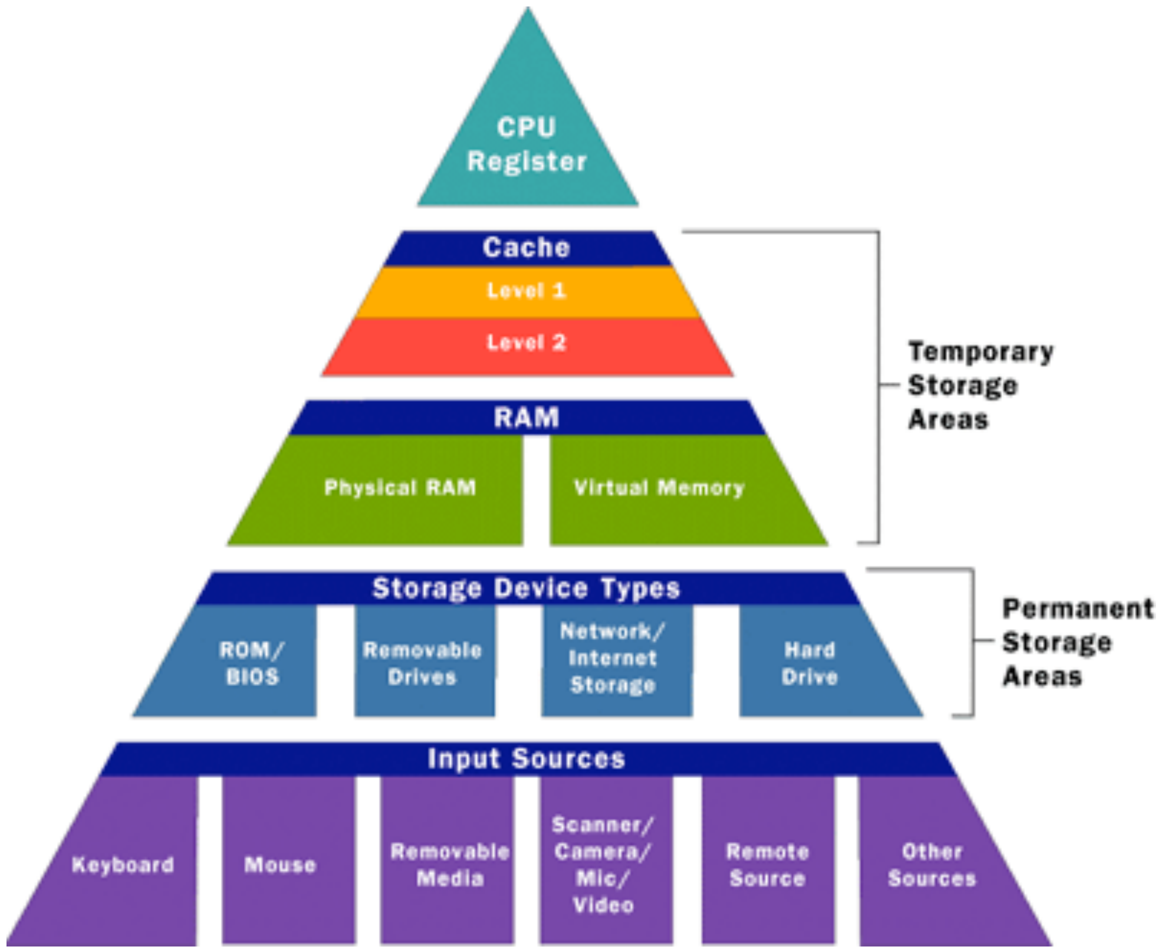
Cache Misses

- Types of misses
  - Compulsory: due to cold cache (happens at beginning)
  - Conflict: When referenced data maps to the same block
  - Capacity: when working set is larger than cache

Locality

- Reason why caches work
- Temporal locality
  - Programs tend to use the same data and instructions over and over
- Spatial locality
  - Program tend to use data and instructions with addresses near to those they have recently used

Memory Hierarchy



Cache Miss Analysis Exercise

- Assume:
  - Cache blocks are 16-byte
  - Only memory accesses are to the entries of grid
- Determine the cache performance of the following:

```
struct algae_position {
    int x;
    int y;
}
struct algae_position_grid[16][16];
int total_x = 0, total_y = 0, i, j;

for (i = 0; i < 16; i++)
    for (j = 0; j < 16; j++)
        total_x += grid[i][j].x

for (i = 0; i < 16; i++)
    for (j = 0; j < 16; j++)
        total_y += grid[i][j].y
```

Techniques for Increasing Locality

- Rearranging loops (increases spatial locality)
- Analyze the cache miss rate for the following:
  - Assume 32-byte lines, array elements are doubles

```
void ijk(A[], B[], C[], n) {
   int i, j, k; double sum;
   for (i = 0; i < n; i++)
      for (j = 0; j < n; j++) {
         sum = 0.0
         for (k = 0; k < n; k++)
            sum += A[i][k]*B[k][j]
         C[i][j] += sum
      }
}
```

```
void kij(A[], B[], C[], n) {
   int i, j, k;
   double r;
   for (k = 0; k< n; k++)
      for (i = 0; i < n; i++) {
         r = A[i][k];
         for (j = 0; j < n; j++)
            C[i][j] += r*B[k][j];
      }
}
```

Techniques for Increasing Locality (cont)

- Blocking (increases temporal locality)
- Analyze the cache miss rate for the following:
  - Assume 32-byte lines, array elements are doubles

```
void naive(A[], B[], C[], n) {
    int i, j, k;
    for (i = 0; i < n; i++)
        for (j = 0; j < n; j++)
            for (k = 0; k < n; k++)
                C[i][j] += A[i][k]*B[k][j];
}
```

```
void blocking (A[], B[], C[], n, b) {
  int i, j, k, i1, j1, k1;
  for (i = 0; i < n; i += b)
    for (j = 0; j < n; j += b)
      for (k = 0; k < n; k += b)
        for (i1 = i; i1 < (i + b); i1++)
          for (j1 = j; j1 < (j + b); j1++)
            for (k1 = k; k1 < (k + b); k1++)
              c[i1][j1] += A[i1][k1]*B[k1][j1];
}
```

Questions?

- Program optimization
- Writing friendly cache code
- Cache lab