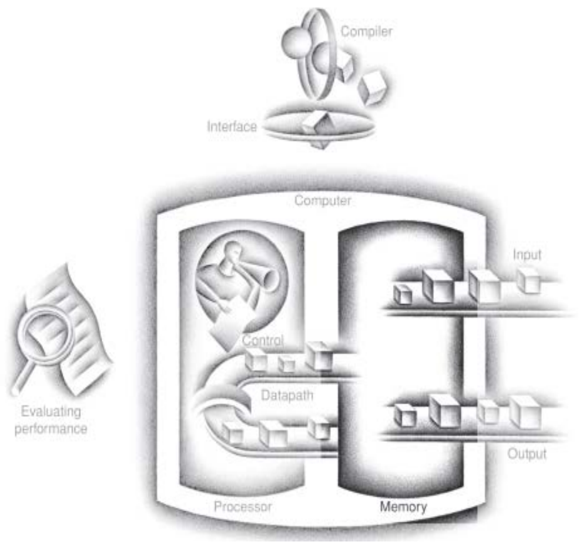
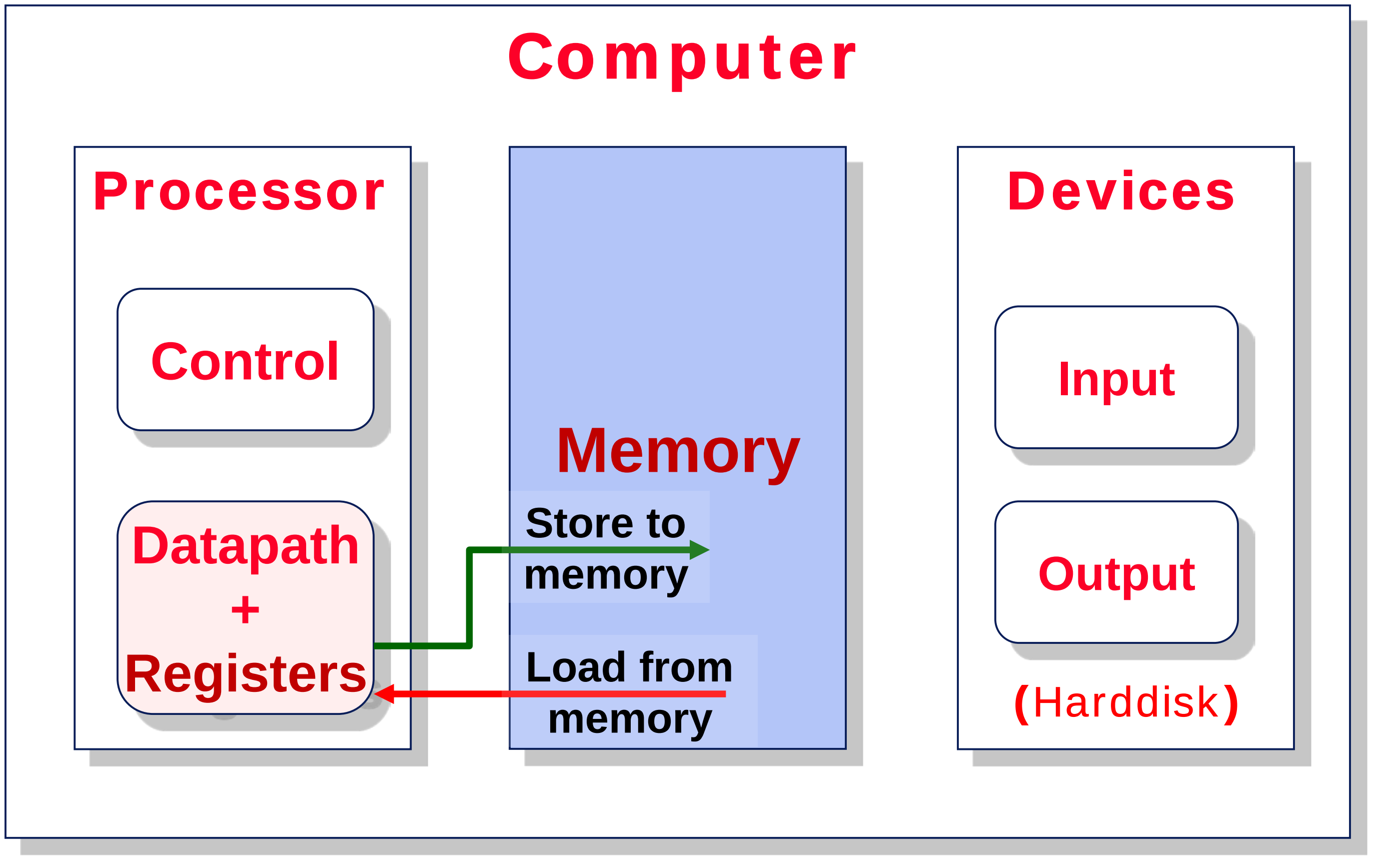
Chapter 5
Large and Fast : Exploiting the Memory Hierarchy

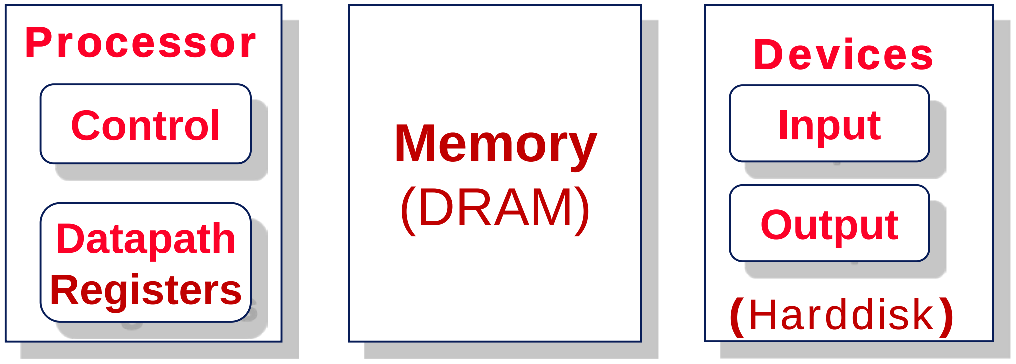


Data Transfer: The Big Picture



Registers are in the datapath of the processor. If operands are in memory we have to **load** them to processor (registers), operate on them, and **store** them back to memory.

Quality vs. Quantity



	Capacity	Latency	Cost/GB
Register	100s Bytes	20 ps	$$$$
SRAM	100s KB	0.5-5 ns	$$$
DRAM	100s MB	50-70 ns	$
Hard Disk	100s GB	5-20 ms	Cents
Ideal	**1 GB**	**1 ns**	**Cheap**

The "Memory Wall"

- Processor vs. DRAM speed disparity continues to grow

- What we want:
  - A **BIG** and **FAST** memory
  - Memory system should perform like 1GB of SRAM (1ns access time) but cost like 1GB of slow memory

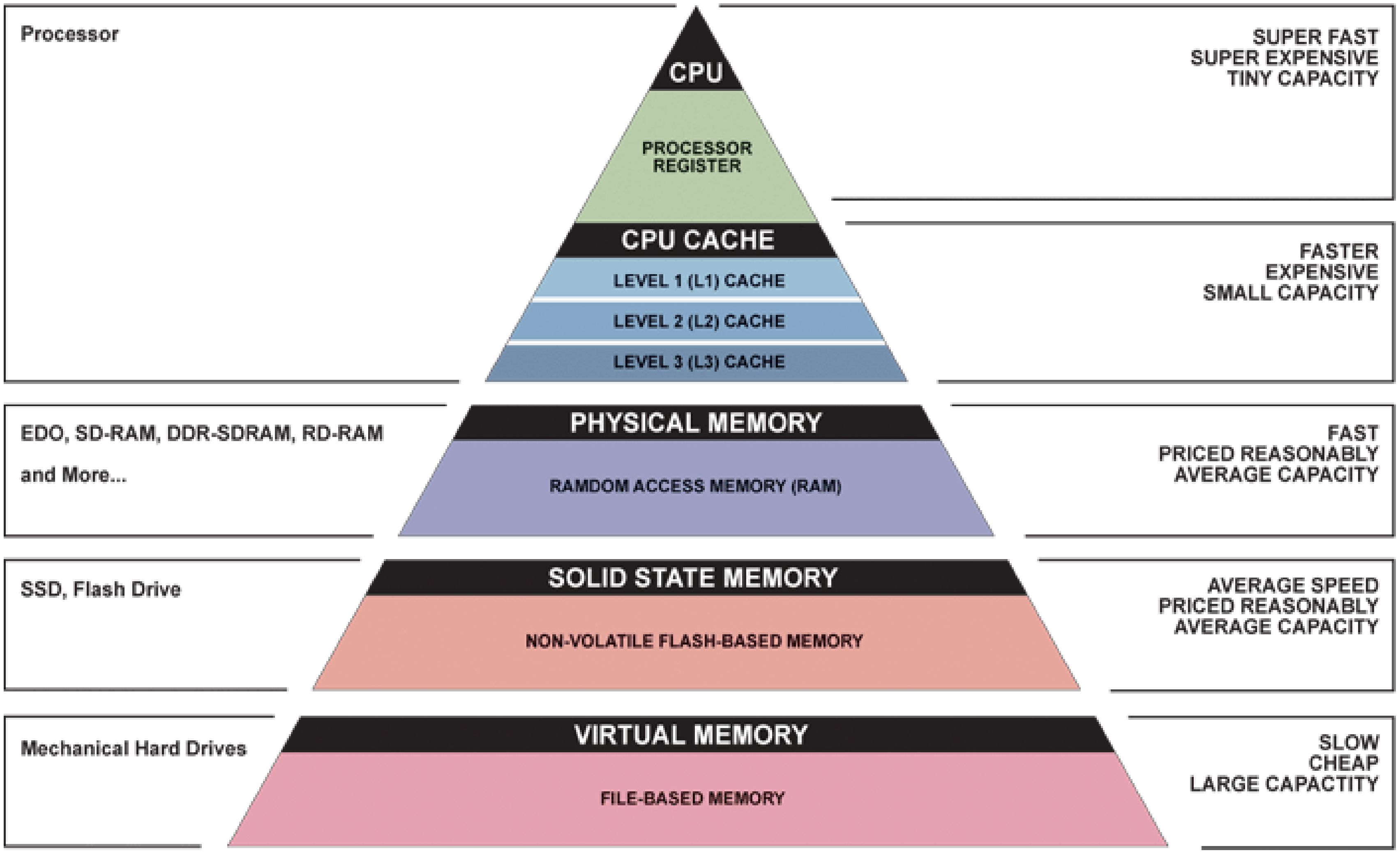
Key concept:

Use a hierarchy of memory technologies:

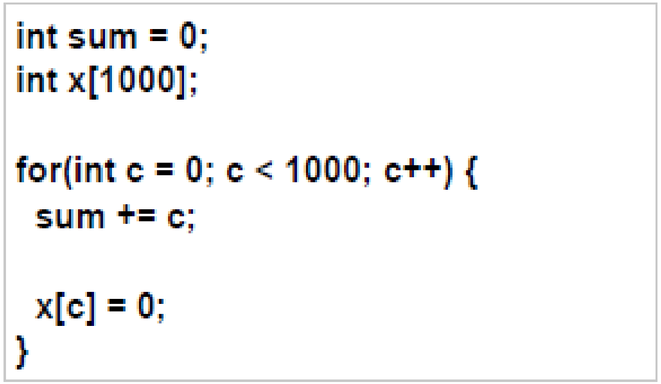
- Small but fast memory near CPU
- Large but slow memory farther away from CPU

- Good memory hierarchy (cache) design is increasingly important to overall performance
  - 1980: no cache in µproc, 1989: first Intel CPU with a cache on chip
  - 1995: 2-level cache on chip 2020 ?

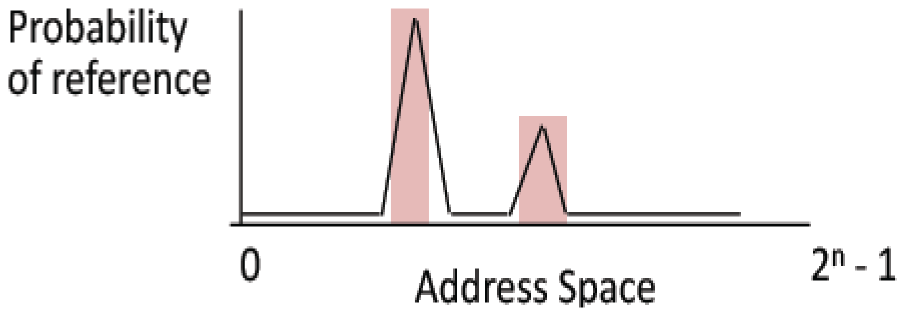
Great Idea : Principle of Locality / Memory Hierarchy



Principle of Locality (pp. 374)



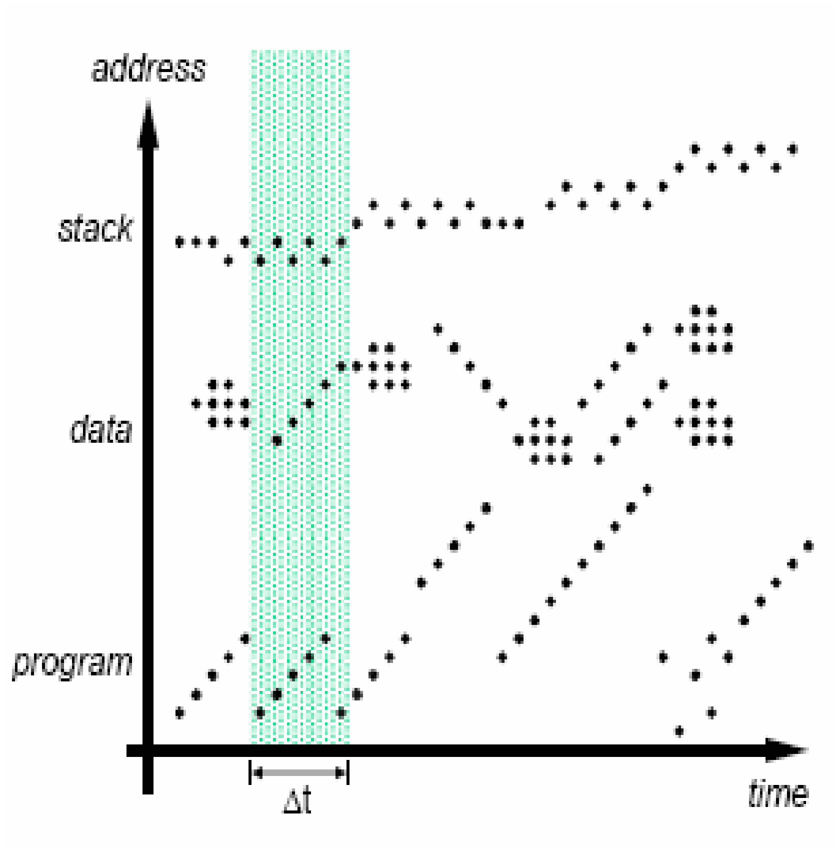
```
int sum = 0;
int x[1000];

for(int c = 0; c < 1000; c++) {
  sum += c;

  x[c] = 0;
}
```



- “Programs will access **only a small proportion** of the address space **at any time**”
  - Not any place accessed randomly with equal probably!
- Temporal Locality (locality in time)
  - Items accessed are likely to be accessed again soon
  - e.g., instructions and data in a loop
- Spatial Locality (locality in space)
  - Items near the accessed item are likely to be accessed soon
  - e.g., sequential instruction access, an array of data

How to Take Advantage of Locality

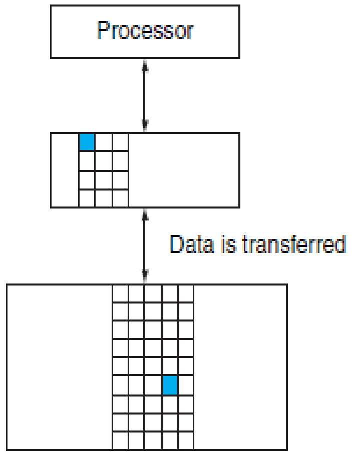
- *Keep most recently accessed data items closer to the processor*
  - Caches   Main memory   Hard Disk



Capture the working set and keep it in the memory closest to CPU

The Memory Hierarchy Levels : Terminology

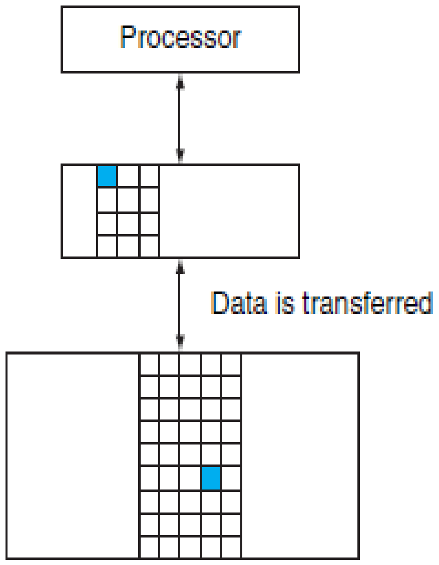
- Block (or cache line): unit of copying
  - It has multiple words



- If accessed data is present in upper level
  - Hit : access satisfied by upper level
  - Hit ratio = #hits / #accesses
- If accessed data is absent
  - Miss : block copied from lower level
  - Miss ratio = #misses / #accesses = 1 - Hit ratio
  - Time taken : Miss Penalty (Time to replace a block in that level with the corresponding block from a lower level)
- Hit Time << Miss Penalty

Common Framework for Memory Hierarchy

- Q1 block placement
- Q2 block identification
- Q3 block replacement
- Q4 write policy
- **Modern systems? Figure 5.44**



Summary