From Programs to Execution

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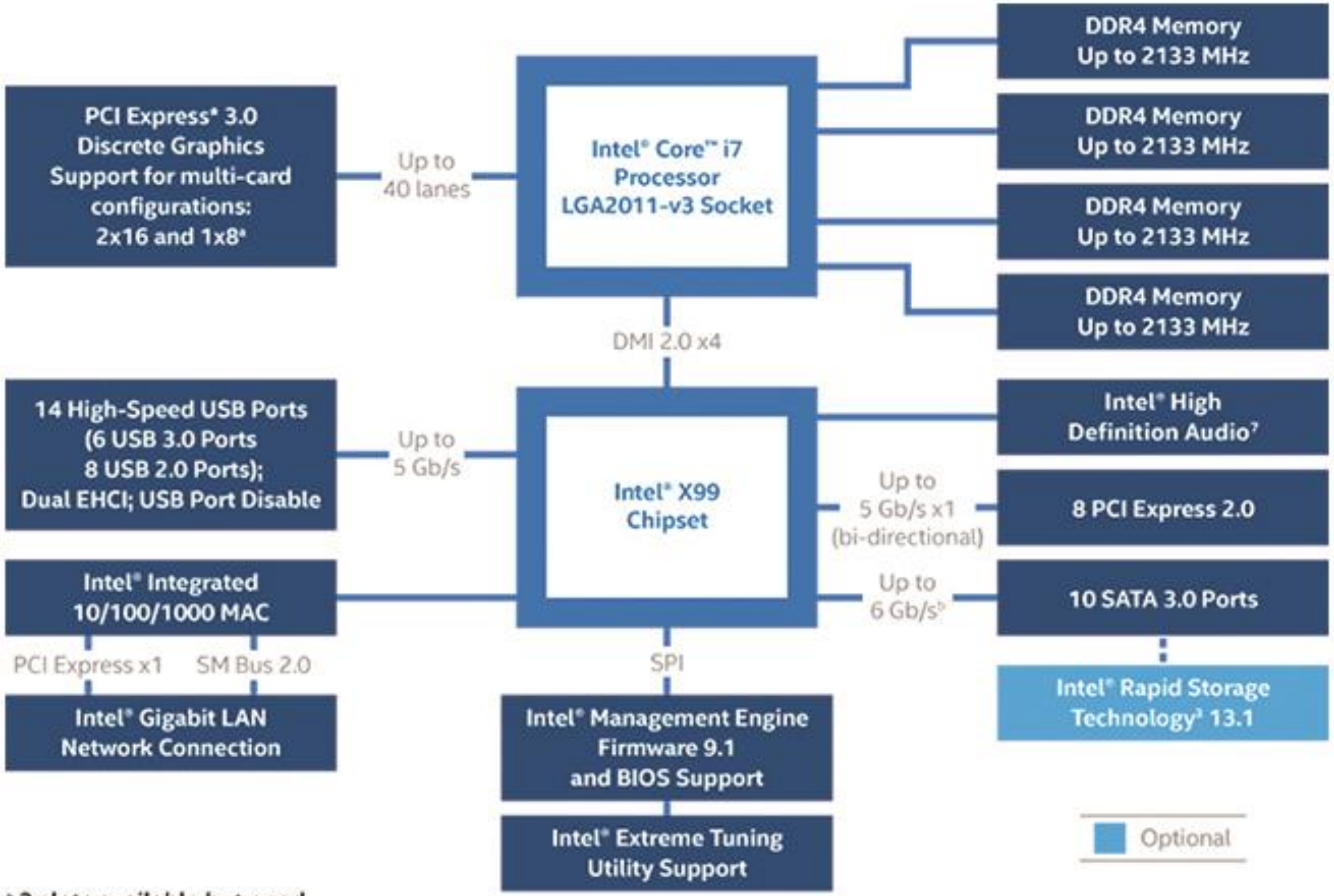
The Underlying Hardware

- The OS provides software access to the hardware in an *abstracted* manner

- What does that hardware actually look like?

In this case, this ancient 3rd party wireless(!) NES hardware looks pretty awesome

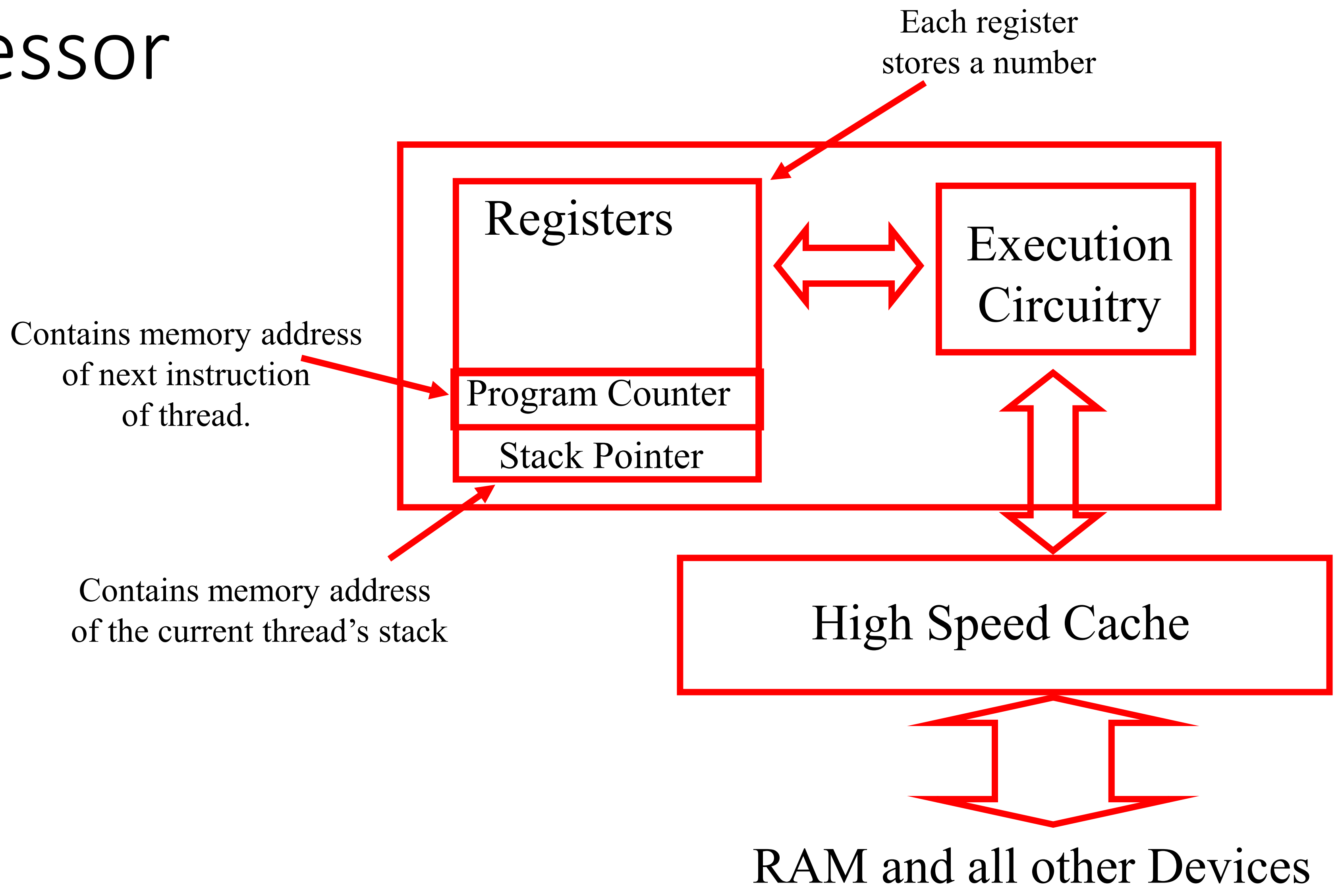
Intel® X99 Chipset Block Diagram



[a] 3 slots available but need additional logic onboard to support more slots. 5x8 configuration requires additional system clocks to be provided by third party components.

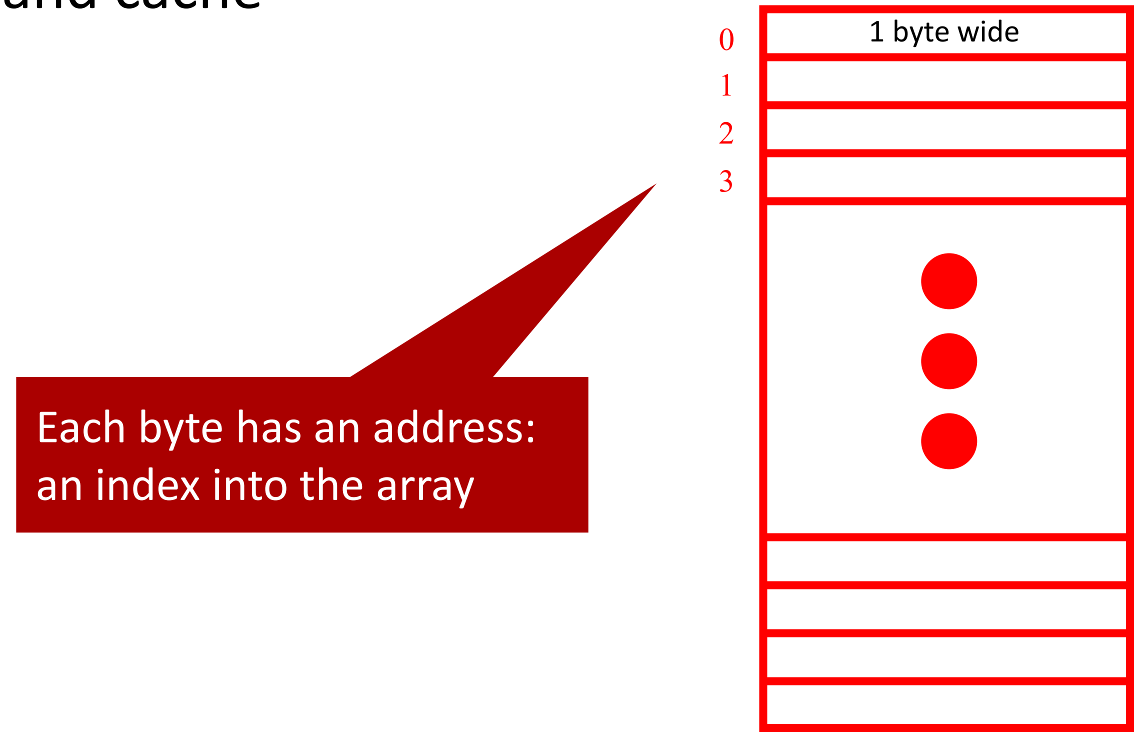
[b] All SATA ports capable of 6 Gb/s.

A Processor


Each register
stores a number
Registers
Execution
Circuitry
Contains memory address
of next instruction
of thread.
Program Counter
Stack Pointer
Contains memory address
of the current thread's stack
High Speed Cache
RAM and all other Devices

Memory

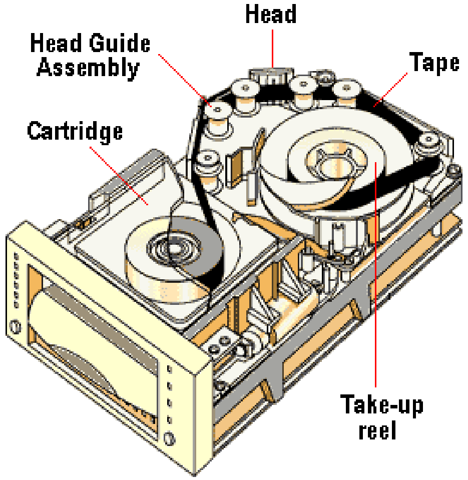
- Memory is an array of *bytes*
- Temporary storage only:
  - Much slower than the processor and cache
  - Much faster than a disk



Other Storage Devices

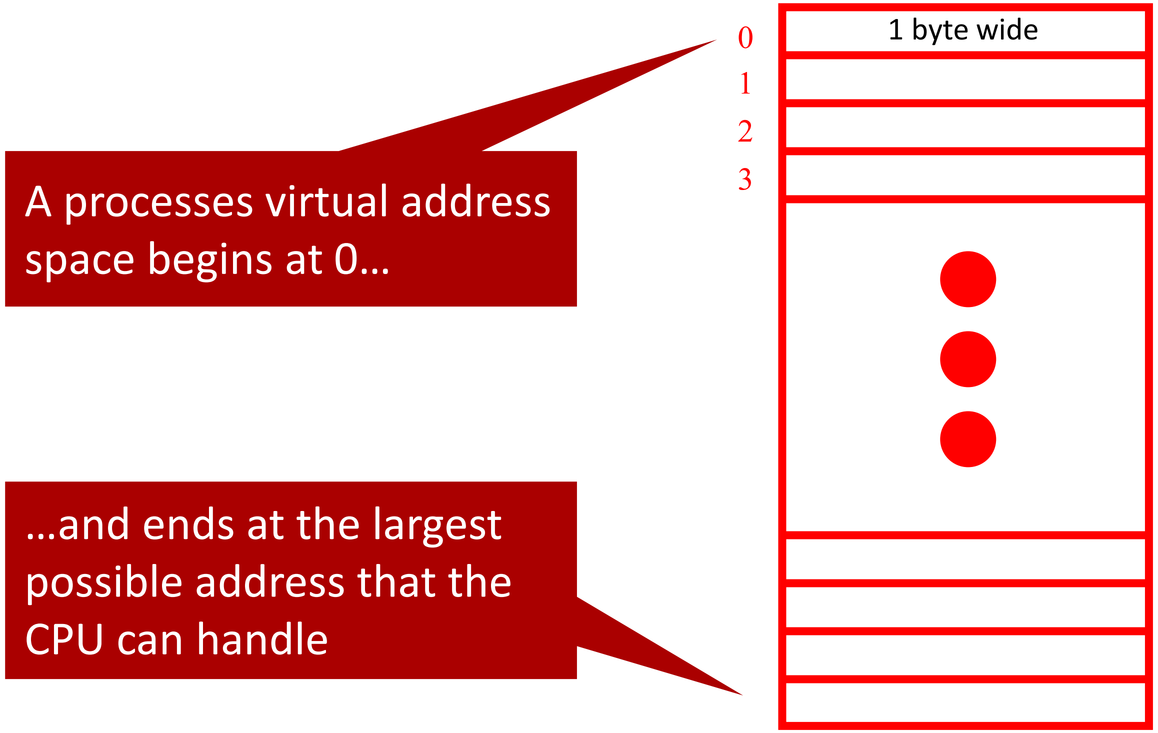
- Persistent storage
    - Magnetic Hard Disk Drives (HDD)
    - Non-volatile memory
        - Solid State Drives (SSD)
        - Flash memory
    - Magnetic tapes
    - Optical (CD-ROM, DVDs, BD, etc.)

- All slower than RAM, but keep their memory without power

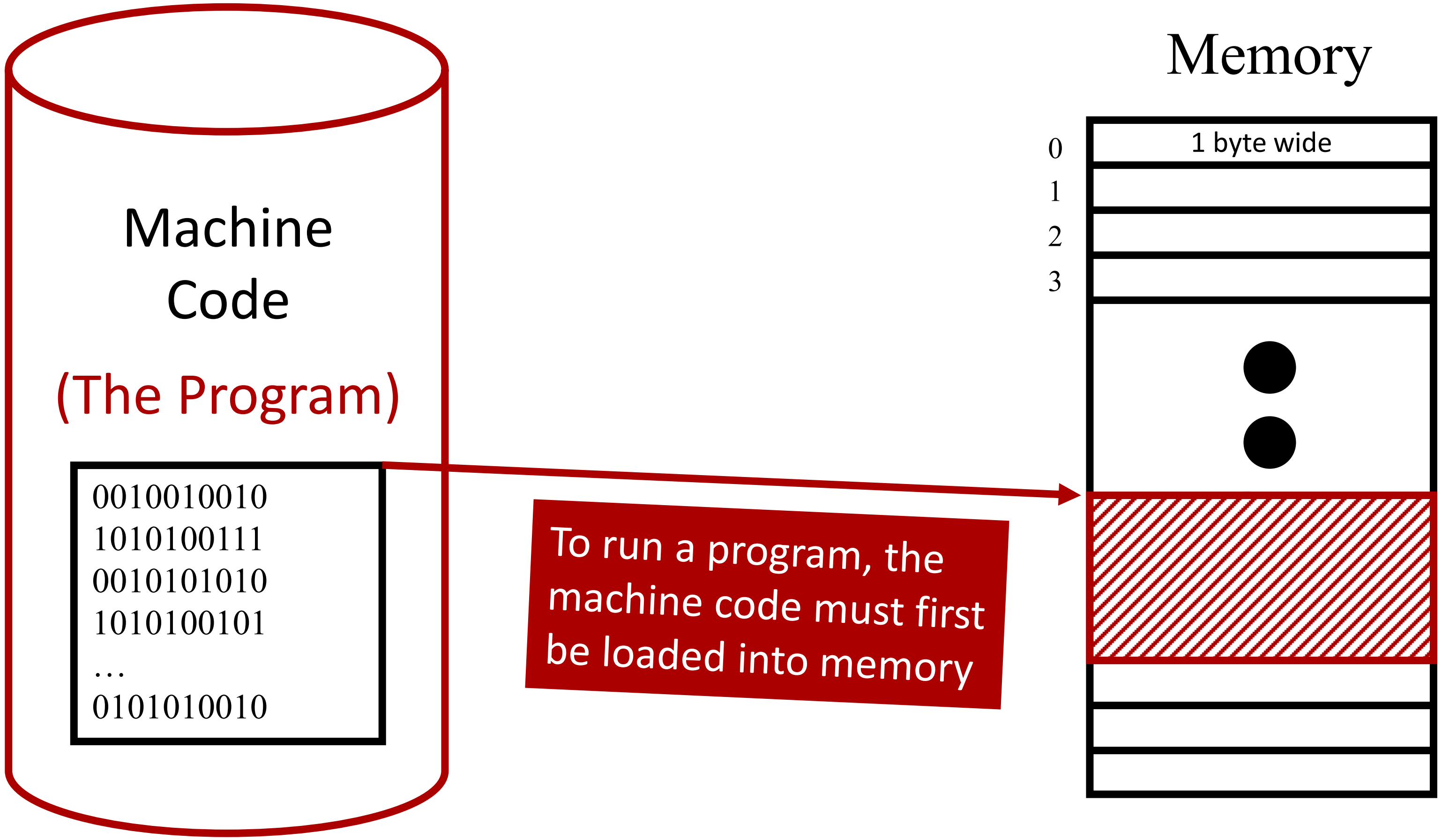


Virtual Memory

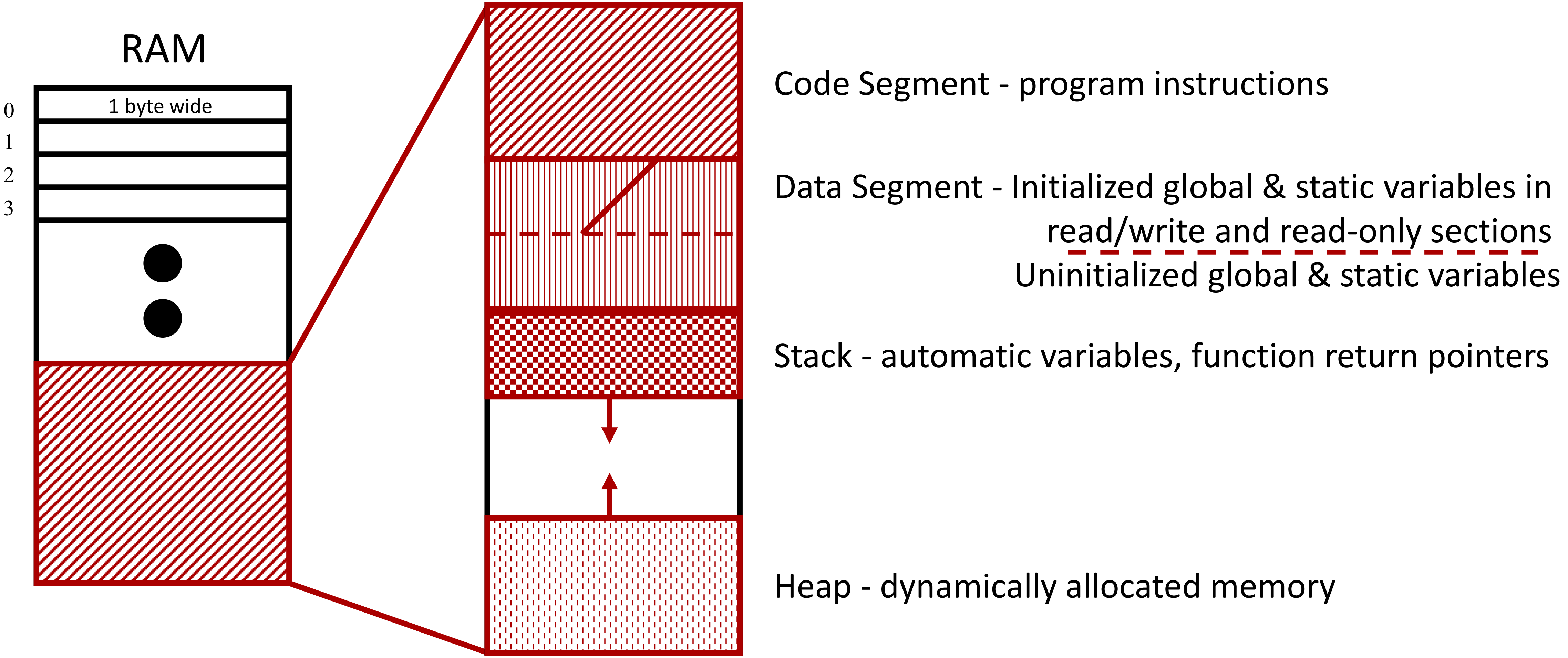
- Virtual memory hardware creates the illusion of:
  - Un-shared, exclusive memory
  - Unlimited memory (up to the maximum address size)



Running a Program



Typical Organization of Program in Memory



Stack Versus Heap

The Stack

- Stores local automatic variables and function return pointers as the program enters and exits scoped blocks of code
- Memory managed efficiently by CPU
- Variable size is limited by OS settings
- Variables cannot be resized

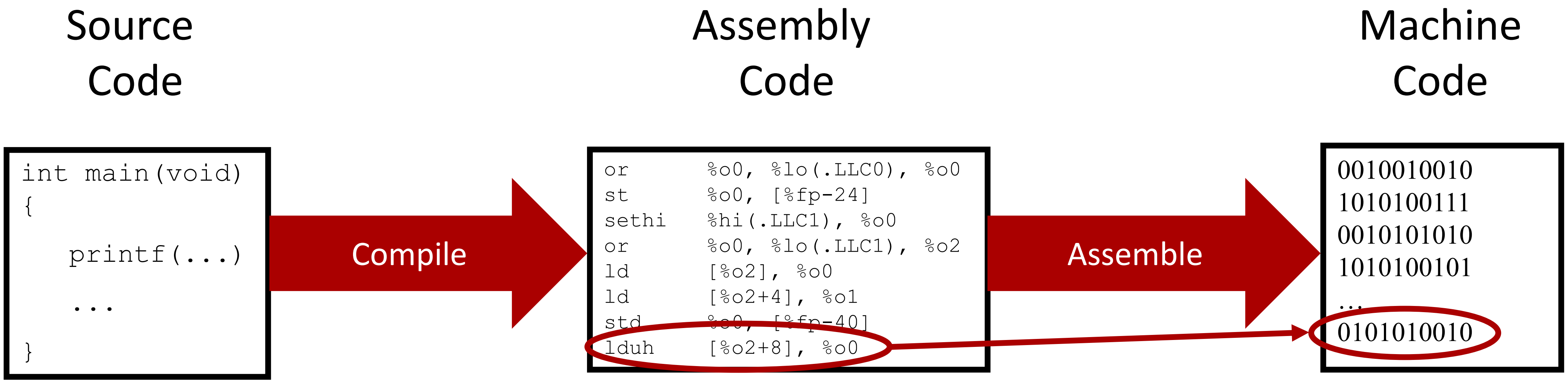
The Heap

- Variables are allocated manually (`malloc()`, `calloc()`)
- Memory is unmanaged, so fragmentation can occur; heap access is slower than stack
- Variable size is unlimited (other than virtual memory limits)
- Variables can be resized with `realloc()`

Creating The Program Code

- How do we turn a high-level program (C++, Java) into something that the computer can run?

Creating The Program Code – High Level



Machine code is just binary
version of assembly instructions

- By default, most compilers will compile, link, and assemble your source code, though you can split those steps up for more control

The compile/link process

1. The C pre-processor expands macros and strips out comments
   `#include`, `#define`, `#ifdef`, `//`, `/* */`, etc.
2. The compiler parses your source, checks for errors and generates assembly language code
3. The compiler calls the assembler, which converts assembly code to machine binary code
4. If you are compiling an executable, the linker step tries to match function calls to function code (they might be in different files!)

GCC - the Standard UNIX Compiler

- Basic compilation options

`-g`	Compile with debugging info for GDB
`-c`	Compiles only, without linking (more later)
`-S`	Generates assembly code
`-O3`	Optimizes as much as possible
`-o`	Specifies the *name* of the output file
`-Wall`	Turns on all warnings
`-l`*`library`*	Adds support for library *`library`* when linking (for example, `-lpthread`)

- These should work with any of the Unix CLI C/C++ compilers

Compiling an Executable

- If you have *one* source (.c) file:

```
$ gcc -o dbtest dbtest.c
```

Here I've used `dbtest`, instead of `test`. Why?

- If you have *multiple* source (.c) files:
  - Option A *(simpler)*: compile them all at once, together into one executable:

```
$ gcc -o dbtest dbtest.c dbcreate.c dbopen.c
```

Separate Compile and Link

- If you have *multiple* source (.c) files:
  - Option B *(more efficient)* : compile them one at a time without linking, then link them all together at the end

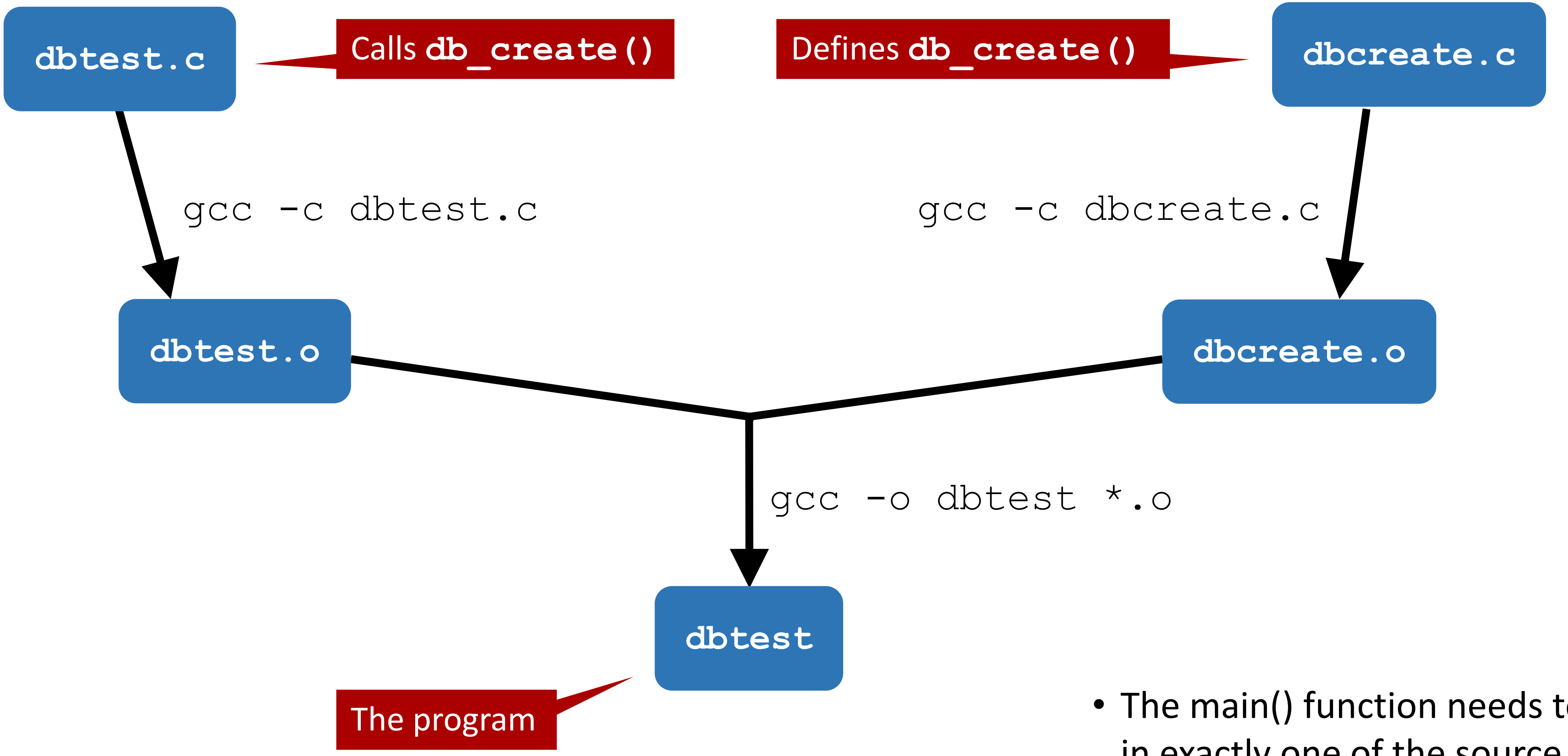
1. First compile all source files separately into object files (.o):

```
$ gcc -c dbtest.c
$ gcc -c dbcreate.c
$ gcc -c dbopen.c
$ gcc -c dbread.c
```

2. Link all the object (.o) files together to create an executable:

```
$ gcc -o dbtest dbtest.o dbcreate.o dbopen.o
```

Compile & Link



- The main() function needs to be in exactly one of the source files

Library Archives

- Library archives are collections of object files (.o) gathered into a single large file, with indexes to make accessing them fast
  - Usually faster than having to read every .o file
  - Easier to link with if you aren't changing the library object files frequently

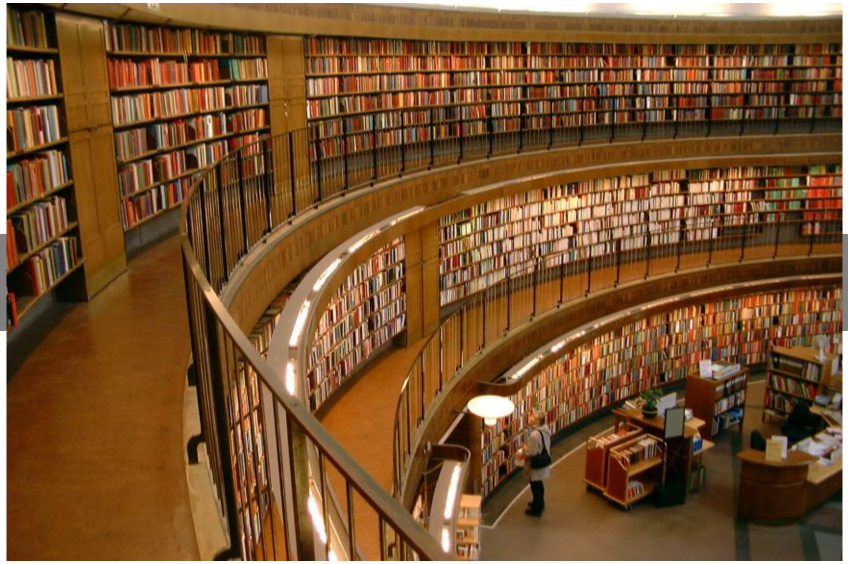
- To create a library
  - First create all the object files (see previous slide)
  - Then use the `ar` command:

```
$ ar -r libdb.a dbcreate.o dbopen.o dbread.o
```

Using Library Archives

- Include the library anywhere you can use an object file:

```
$ gcc -o dbtest dbtest.o libdb.a
```



Hello World!

- A complete C compilation and execution example:

```
$ cat hw.c
#include <stdio.h>

void main()
{
        printf("Hello World!\n");
}
$ gcc -o hw hw.c
$ hw
Hello World!
```