Linking, Loading, and Shared Libraries

Martin Kellogg

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  - but you're required to include a dataflow analysis for DCE in your eventual PA4 submission, so we recommend using PA4c1 as an excuse to do it
- I will be around this afternoon ~4:30pm if you want to see a test case
  - PA3 test case views can still be used

Agenda

- Review + finish global register allocation
- And then...
  - Object Files
  - Linking
  - Relocations
  - Shared Libraries
  - Separate Typechecking

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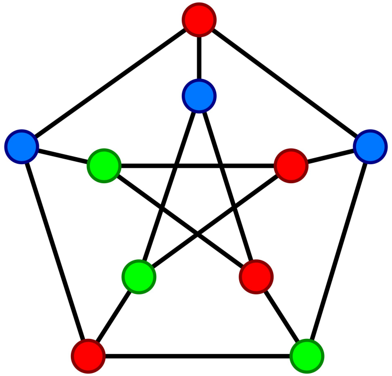
  - critical edges are one complication on basic block boundaries
  - instead, a **global** allocator can coordinate assignments across basic blocks

Review: Global Register Allocation



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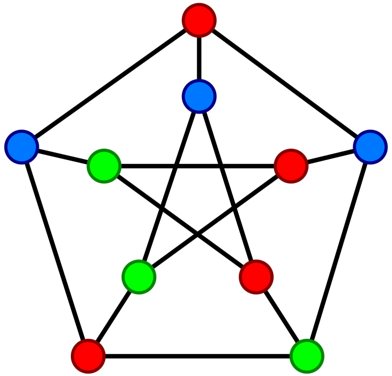

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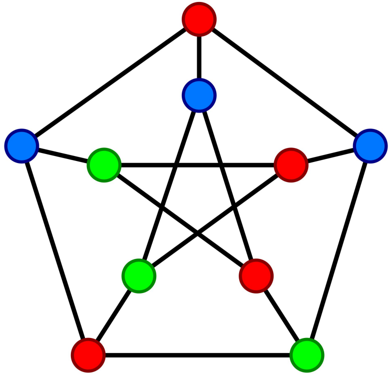

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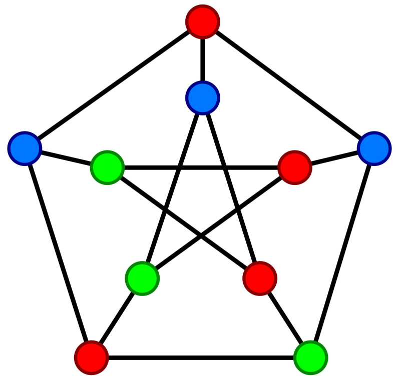

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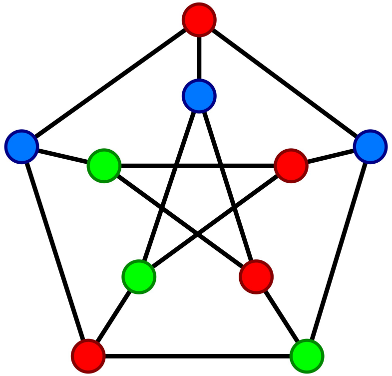

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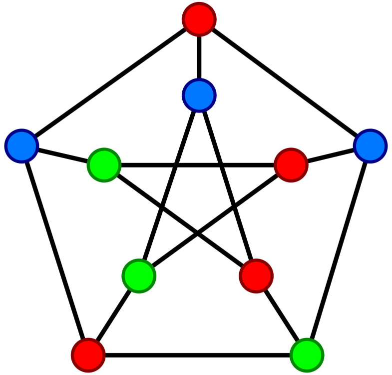

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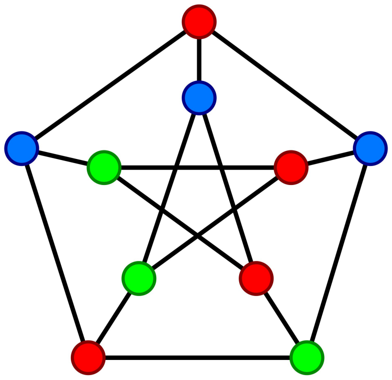

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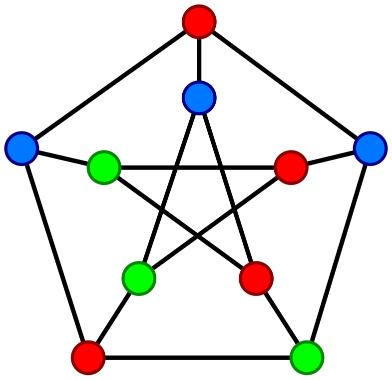

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    - nodes in this graph are values, edges represent values that are simultaneously live
    - it is easy to construct this graph from live ranges
- Next, we will **actually color** this graph

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    - To be clear: this approach is **heuristic** (graph coloring is NP-complete). You could solve the graph coloring problem here using any graph coloring algorithm.

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- More formally, if the simplified graph is ***K-colorable***, then so is G: since n has less than K neighbors, those use at most K-1 colors, and there is therefore at least one color available for n.

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When a node is really spilled, the program has to be rewritten, which changes the interference graph. When this happens, the allocation process must be **restarted completely**. In practice, it converges in one or two iterations in most cases.

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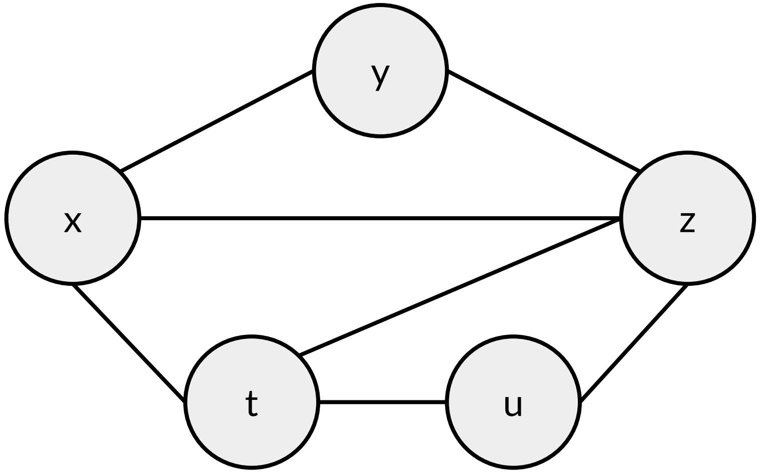

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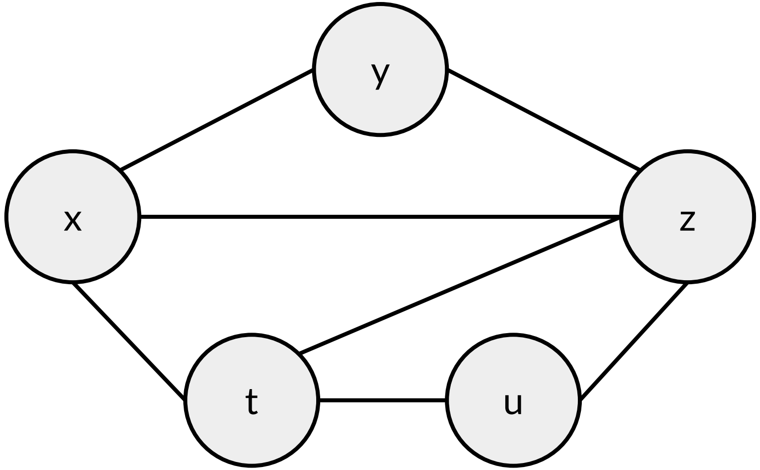

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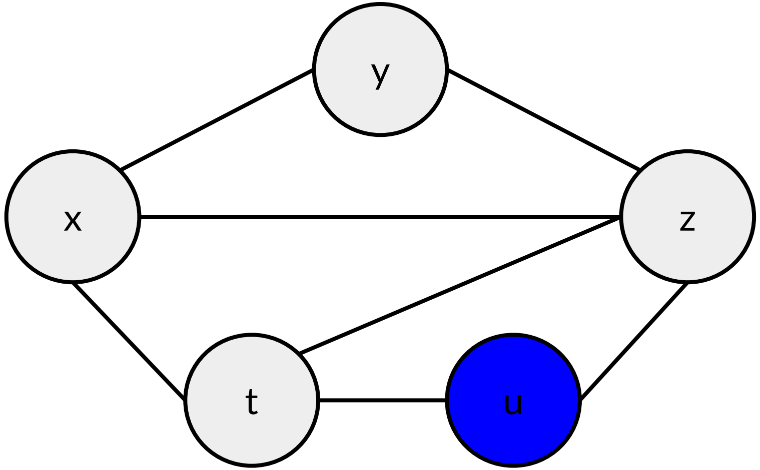

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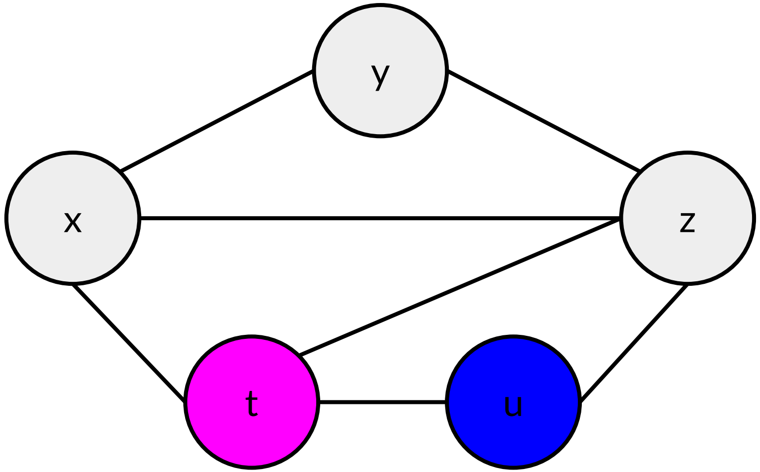

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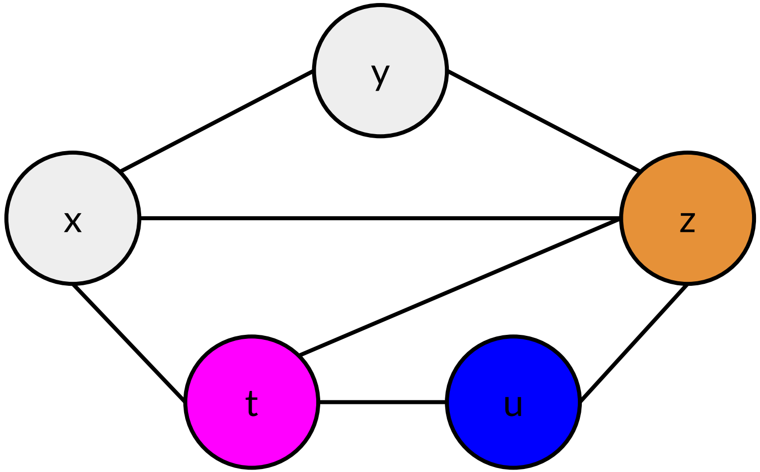

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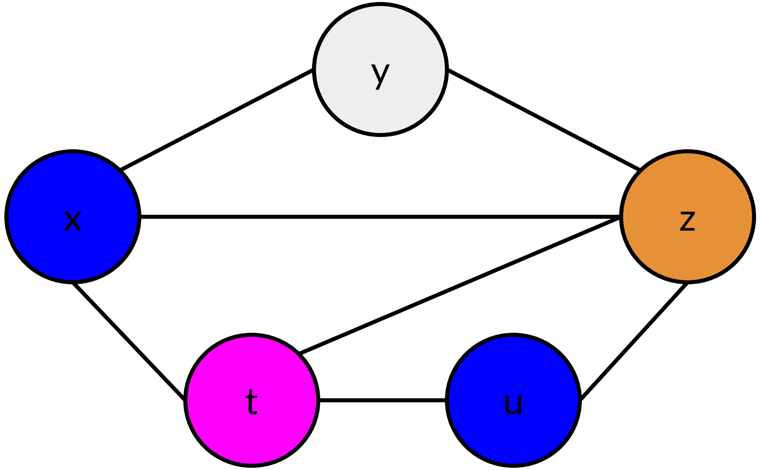

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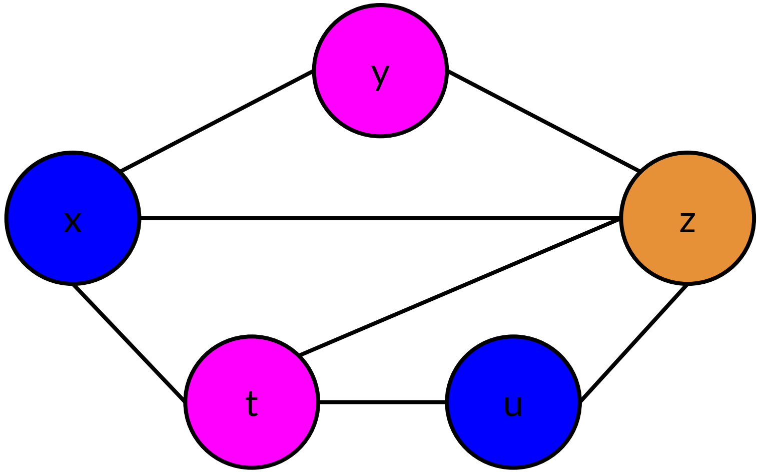

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  - Object Files
  - Linking
  - Relocations
  - Shared Libraries
  - Separate Typechecking

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  - Compilers/languages that do not support separate compilation are **not useful** in practice (RIP Cool)

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  - compiler : source code -> assembly
  - assembler : assembly -> object file
  - linker : object files -> binary

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- Linking involves two tasks:
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  - **Resolving references** (e.g., to variable locations or jump-target labels) so that they point to concrete and correct virtual addresses in the ~~New World Order~~ program's virtual address space

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So Many Tables!

- these tables contain **a lot** of information…
- tables also must be easy to understand…
- maybe an example will help

Relocatable Object Files: Example

- Consider this C program:

```
extern double sqrt(double x);

static double temp = 0.0;

double quadratic(double a, b, c) {
        temp = b*b – 4.0*a*c;
        if (temp >= 0.0) { goto has_roots; }
        throw Invalid_Argument;
has_roots:
        return (–b + sqrt(temp)) / (2.0*a);
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0x1000	…
0x1004	push r1
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    temp =
    if (temp >=
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Import Table:
Replace address used at 0x1008 with the final location of **sqrt**

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Export Table:
We provide **quadratic**. If others want it, they can figure out where 0x0200 is finally relocated to. Call that new location R. They then replace all of their references to $loc_{quadratic}$ with R.

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0x0600	r1 =	ld loc_{temp}
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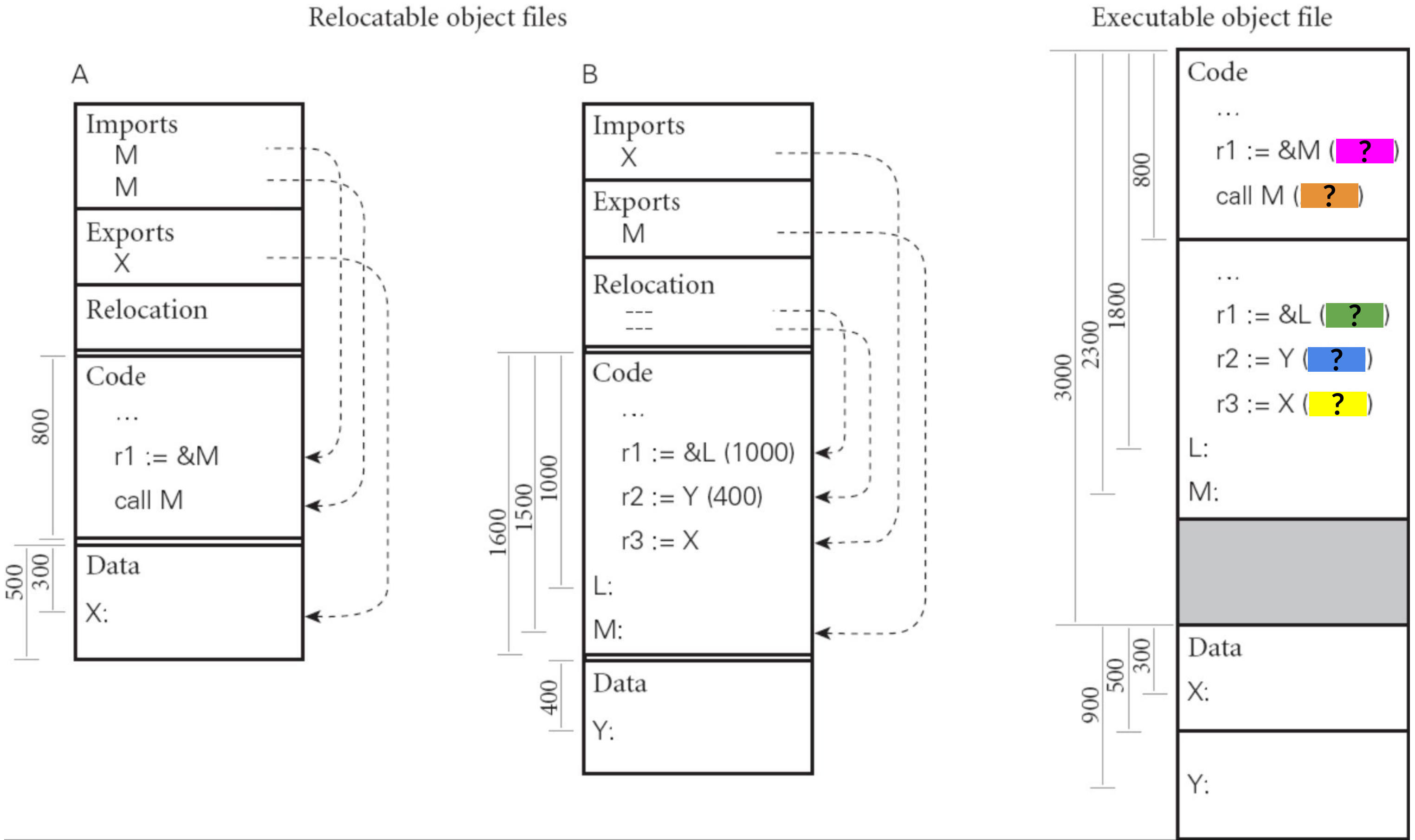
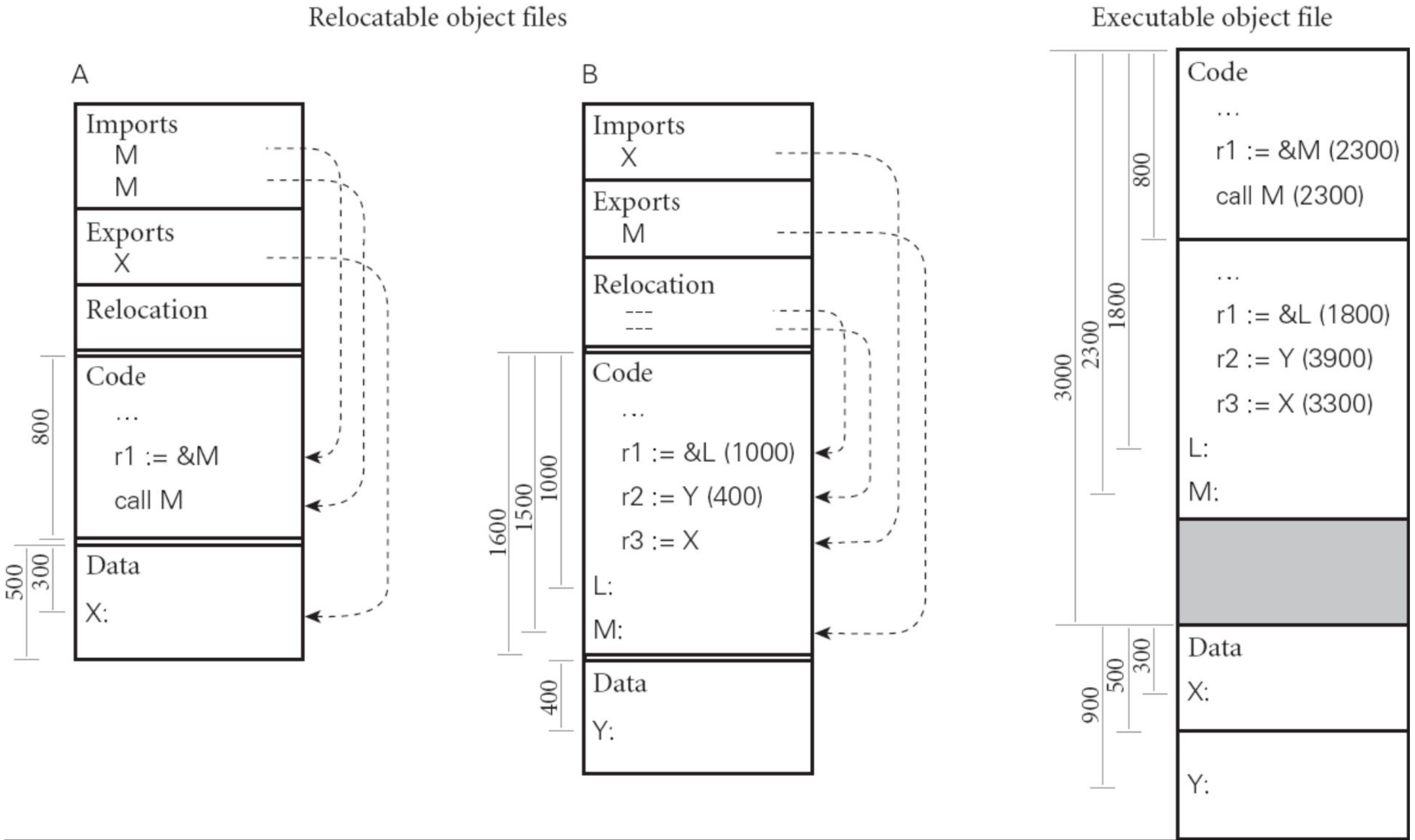
Relocation Table:
Find final relocated address of temp. Call that R_{temp}. Find final relocated address of 0x0600. Call that R_{0x0600}. Replace address referenced at R_{0x0600} with R_{temp}.

Big Linking Example (On Paper w/ a Friend)



Big Linking Example (Answers)



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  - Libraries themselves **can have imports**: example?
  - In Unix, math.o lives in libmath.a and –lmath on the command line will find it
- The linker reads them in, picks a fixed final relocation address for all code and data **(1st pass)** and then goes through and modifies every instruction with a symbol reference **(2nd pass)**

Trivia Break: Philosophy

This Athenian philosopher authored no texts and is known mainly through the posthumous accounts of classical writers, particularly his students Plato and Xenophon. These accounts are written as dialogues, in which this philosopher and his interlocutors examine a subject in the style of question and answer. He was a polarizing figure in the Athenian society of the day; in 399 BC, he was accused of impiety and corrupting the youth. After a trial that lasted a day, he was sentenced to death. He spent his last day in prison, refusing offers to help him escape. Despite this, he has exerted a strong influence on philosophers in later antiquity and has continued to do so in the modern era.

Trivia Break: Philosophy

This family of normative ethical theories prescribes actions that maximize happiness and well-being for the affected individuals. In other words, these theories encourage actions that lead to the greatest good for the greatest number. The seeds of the theory can be found in the hedonists Aristippus and Epicurus (who viewed happiness as the only good), the state consequentialism of the ancient Chinese philosopher Mozi (who developed a theory to maximize benefit and minimize harm), and in the work of the medieval Indian philosopher Shantideva. Modern proponents include Jeremy Bentham, John Stuart Mill, Henry Sidgwick, R. M. Hare, and Peter Singer.

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- How could we go about **sharing** math.o?

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- Idea: ***shared libraries*** (.so) or ***dynamically linked libraries*** (.dll, .dylib) use virtual memory so that multiple programs can share the same libraries in main memory

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- What could **go wrong** with this plan? Code? Security?

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- So either:
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  - math.dll uses **no relocations** in its **code segment** (how?)

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  - You tell me:
    - Where should they live?
    - Should they be shared?

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- The entry point to a shared library (or the caller) sets register GP to hold *B*
  - Optimization: if the code and data live at fixed offsets, can do e.g. GP = ((PC & 0xFF00)+0x0100)

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  - And thus your own base address *B* to put in GP
  - Optimization: use ***copy-on-write*** virtual memory
- Detail: use an **extra level of indirection** when the PIC shared library code does **callbacks** to unshared main() or references global variables from unshared main()
  - Allows the unshared non-PIC target address to be kept in the data segment, which is private to each program

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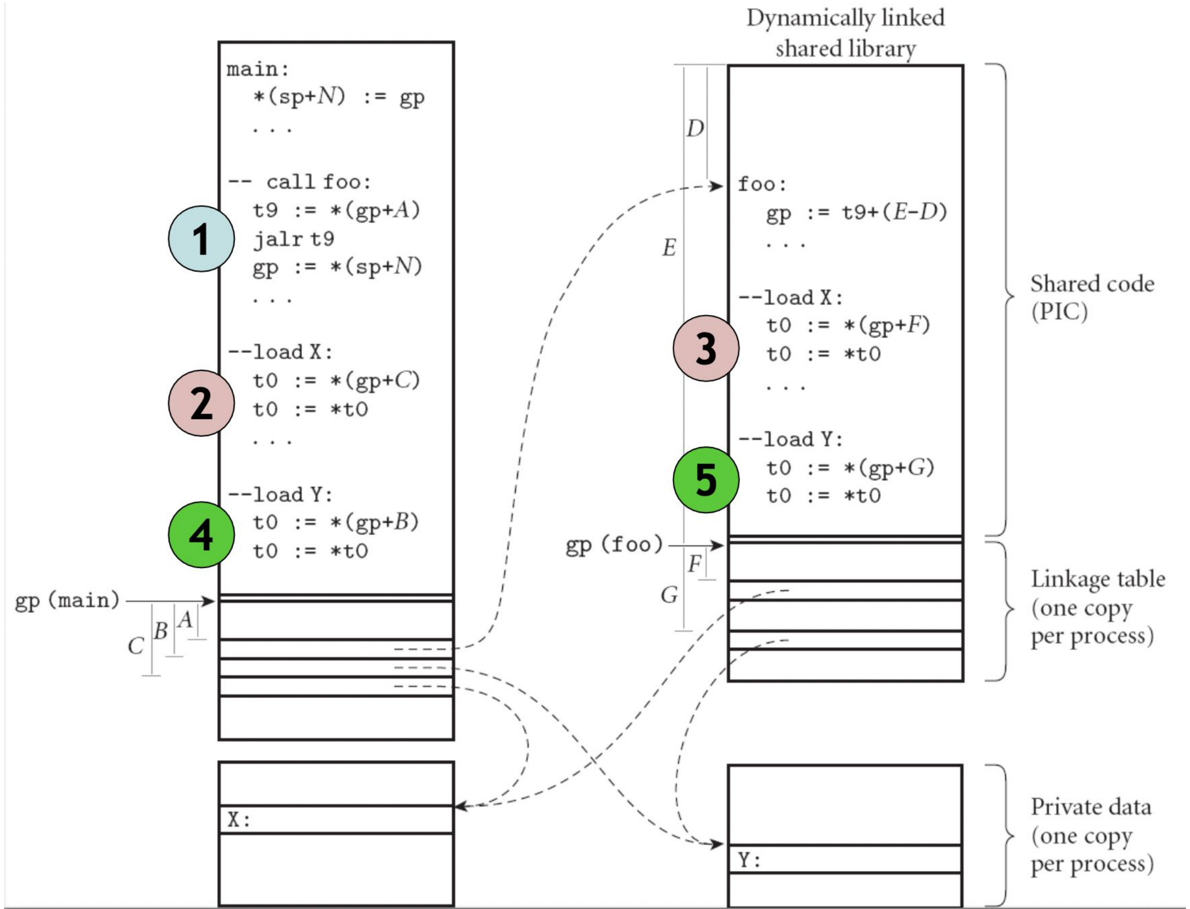

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- Use linkage table as before
  - But instead loading the code for foo(), point to a special **stub procedure** that loads foo() and all variables from the library and then updates the linkage table to point to the newly-loaded foo()

Typechecking

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- But, do we have them **safely**? Consider the following:

```
(* Main *)

extern string sqrt();
void main() {
  string str = sqrt();
  printf("%s\n",str);
  return;
}
```

```
(* math *)

export double sqrt(double a) {
     return ...;
}
```

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    - Listing all exported globals ***and their types***
    - The imp map and class map from PA2 suffice perfectly: just throw away the expression information
- When we compile a client of a library we check the interface file for the types of external symbols
    - Can anything **go wrong** with this plan?

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  - ...
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How might we **prevent** this from happening (even accidentally)?

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  - Include this hash value in the relocatable object
- Each library client also computes the hash value based on the interface it was given

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    - Include this hash value in the relocatable object
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  - C++ ***name mangling*** is the same idea, but done on a per symbol basis (rather than a per-interface basis)

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- We also wanted to **typecheck** separately-compiled modules.
  - We distribute header files with typing information and a checksum that ensures integrity