Build Systems

Martin Kellogg

Announcements

- IP2 grading in progress
  - remember you have two personal late days, so it's not too late to submit
- Revised project proposals due next Monday
  - this is a very important doc: it's the contract between you and I about what your project will entail
- Don't forget about "Your Choice" readings
  - you'll have to do a reading quiz for one of them as part of the exam on October 27 (also: discuss exam review)

Build Systems

Today's agenda:

- **Finish slides on Languages**
    - multilanguage projects, performance, team and process factors, when to rewrite
- What is a build system? How does one work?
- How to choose a build system + best practices
- Reading Quiz

Multi-language projects

C/C++ is a lingua franca

- In a given project, not all code needs to be written in the same l
- N anguage for e
  - but complicate many parts of software engineering
- Traditional architecture:
  - Application **kernel** is written in a statically typed, optimized, compiled language
  - **Scripts** are written in a dynamically typed, interpreted language

Examples: Emacs (C / Lisp), Adobe Lightroom (C++ / Lua), NRAO Telescope (C / Python), Google Android (C / Java), most games (C++ / Lua), etc.

Multi-language projects

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  - enables easy integration and interoperability

Multi-language projects

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  - enables easy integration and interoperability
- Examples:
  - .NET framework (Microsoft)
    - C++, C#, J#, F#, Visual Basic, etc.
  - Java bytecode + Java virtual machine
    - Java, Scala, Kotlin, Closure, etc.
  - LLVM bytecode
  - etc.

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  - Must understand types (etc.) in **all** languages

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- **Developer expertise** is required in multiple languages
  - Must understand types (etc.) in **all** languages
- Most **tools are language specific**: testing frameworks (+ generation, coverage, etc.), static analysis, build systems, debuggers, etc.

How can programming languages differ?

- programming paradigm
- whether they have a type system
  - and, if they do, what kind of type system they have
- library support
  - the standard library is especially important
- **performance**
- team/process factors
  - how well do you know the language
  - how easy it'll be to hire other developers who do

Language performance

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  - Rust: good performance and safety, hard to write
  - Python: easy to write, okay safety, slow
  - C: good performance, easy-ish to write, very unsafe

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    - garbage collection: memory safety
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- #1: **safety features enforced at run time**
  - dynamic type checking: type safety
  - **garbage collection**: memory safety
  - exceptions: segfault safety
- Also relevant: **optimizations**
  - **interpreted** languages almost always slower: no optimizing compiler
  - JITs (***just-in-time compilers***) can produce surprisingly fast code
    - e.g., Java Virtual Machine

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  - requires **static analysis** (= there will be false positives)
  - harder for programmers (trades off against effort)
    - the garbage collector in Java/Go/etc. is automatic
    - but writing Rust code requires follows its (complex) type discipline
  - bottom line: statically safe languages **can be faster**, but are **generally harder to program in**

How can programming languages differ?

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  - and, if they do, what kind of type system they have
- library support
  - the standard library is especially important
- performance
- **team/process factors**
  - how well do you know the language
  - how easy it'll be to hire other developers who do

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  - Becoming an expert takes a long time!
- If you need performance, you usually need **at least one expert**
  - cf. AWS employs some JVM experts to tune the garbage collector for AWS services that use Java

Team/process factors

- Learning a new programming language takes time
  - ... program

> **Implication**: if you're going to need an expert, make sure you have one! This often seriously limits your choice of languages in practice :(

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  - it's **easier to hire** new engineers who already know the language, and therefore can ramp up faster
  - but this impact is relatively small over a typical engineer's tenure at a company
- Implication: if all else is equal, **choose the more popular** language

When to rewrite

- the reading talked about moving a service from one language to another
  - why?

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  - you're not building new features
  - integration problems
  - will the benefits be worth it?

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  - why? **Performance problems**.
- This is usually a **risky thing** to do:
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  - will the b

Implication: rewriting is a good idea if you're confident that the benefits of the new language are worthwhile, but be cautious: it can expensive!

Takeaways

- there is a wider world of languages than just imperative and object-oriented (but those are the most popular)
    - learning to write functional code can make you a better programmer
- different programming languages have different trade-offs
    - performance vs safety vs ease of use vs …
- when starting a new project, think carefully about the requirements before choosing a language
- rewrite a project in a new language only after careful consideration

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- **What is a build system? How does one work?**
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What does a developer do?

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- Compile the code
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- Run tests
- Create artifacts for customers
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From the reading

“Here's how most clients I work with build a project:

1. Open the IDE
2. Load the solution
3. Get latest
4. Press F5 (or CTRL+SHIFT+B)”

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Key objective of a build system: avoid this problem!

What to do instead?

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Orchestrate with a build system!

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- Getting the source code
- Installing dependencies
- Compiling the code
- Running static analysis
- Generating documentation
- Running tests
- Creating artifacts for customers
- Shipping!

A good build system handles all these

Tasks

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- Creating artifacts for customers
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All tasks!

Tasks

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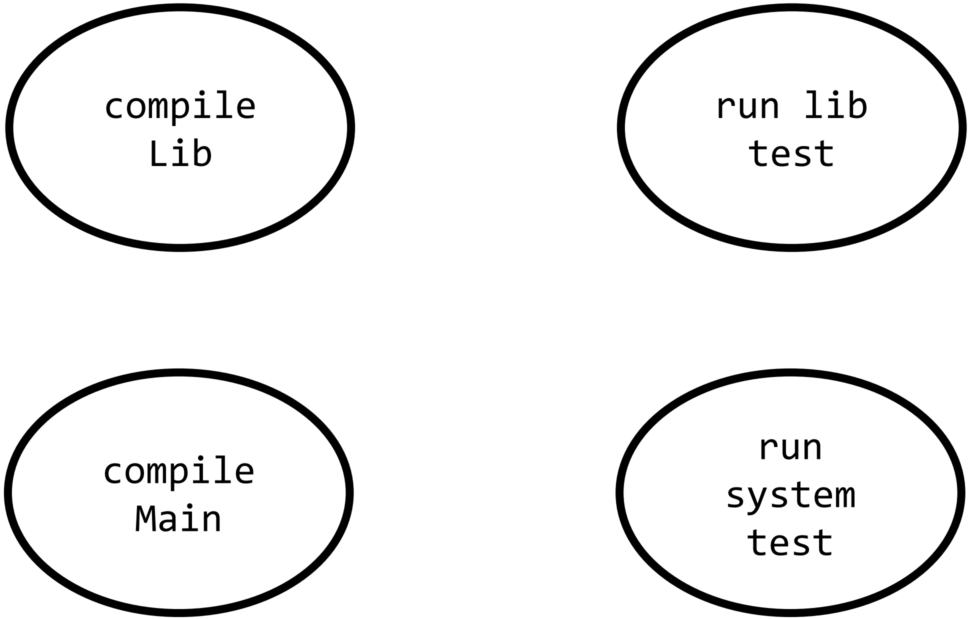
- #1 thing to know about tasks: **tasks are code**, too!
  - Should be checked into version control
  - Should be code-reviewed
  - Should be tested
- Tasks also commonly have **dependencies**
  - Dependency management is a key build system responsibility!

Dependencies between tasks

```
> ls src/

Lib.java   LibTest.java   Main.java    SystemTest.java
```

Dependencies between tasks



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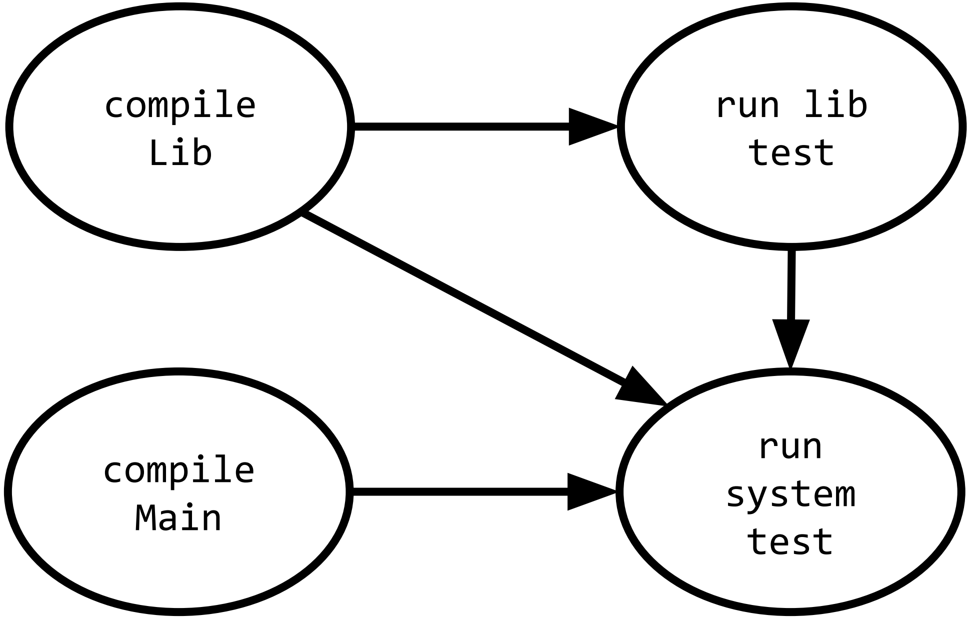

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Topological sort!

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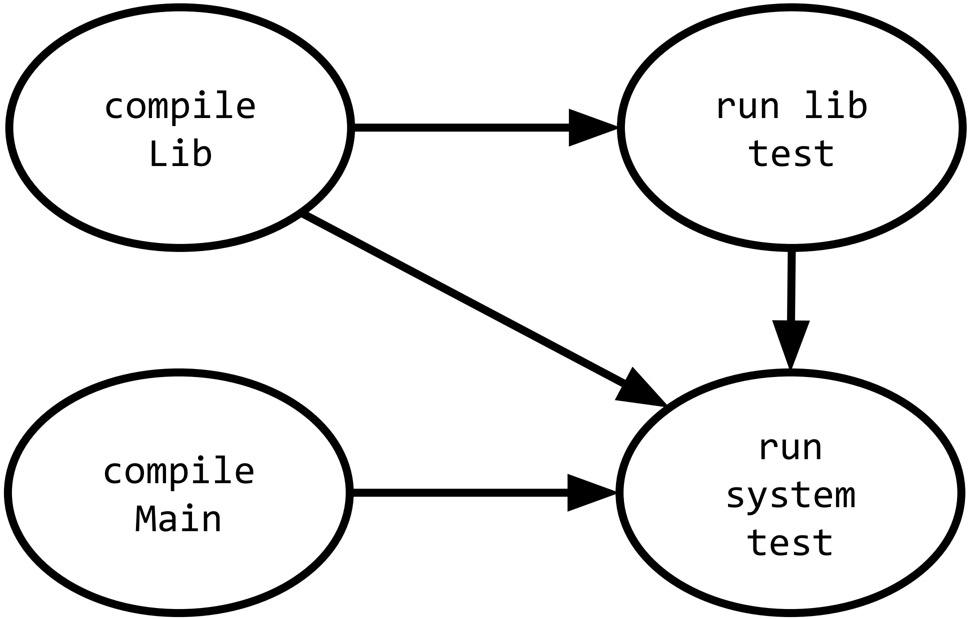
- Implement by computing ***indegree*** (number of incoming edges) for each node

Topological sort



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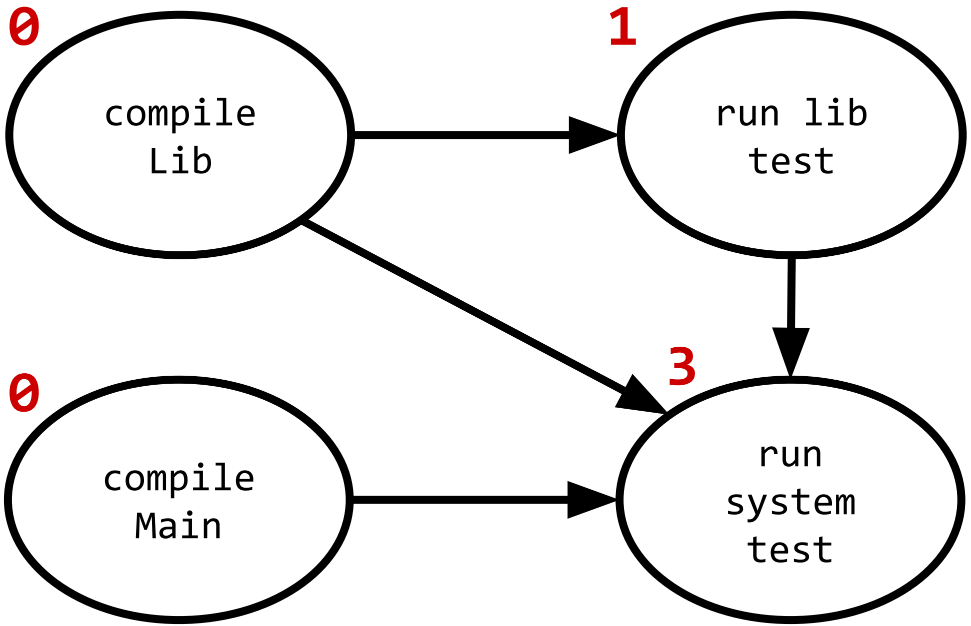

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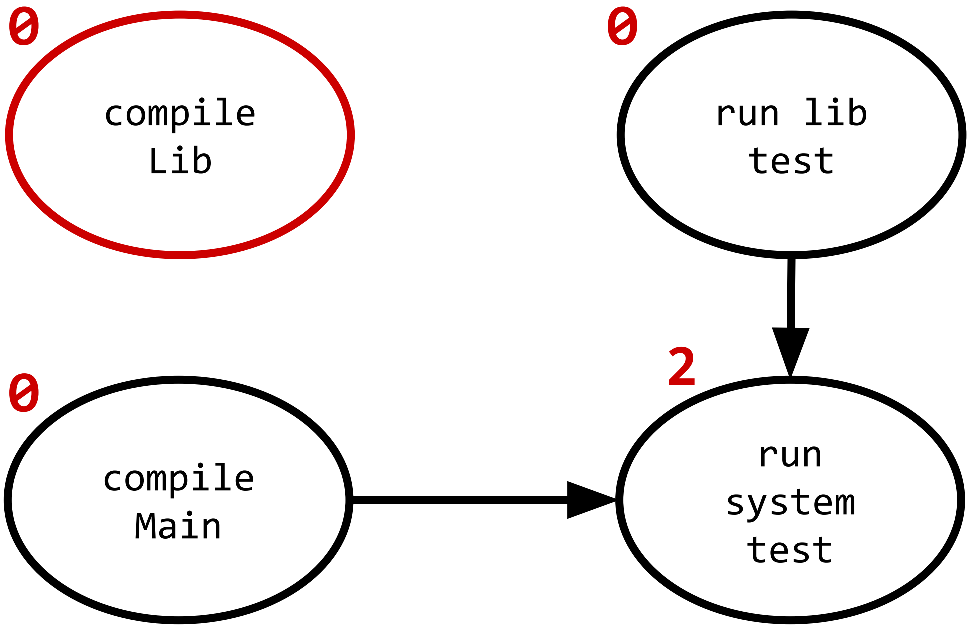

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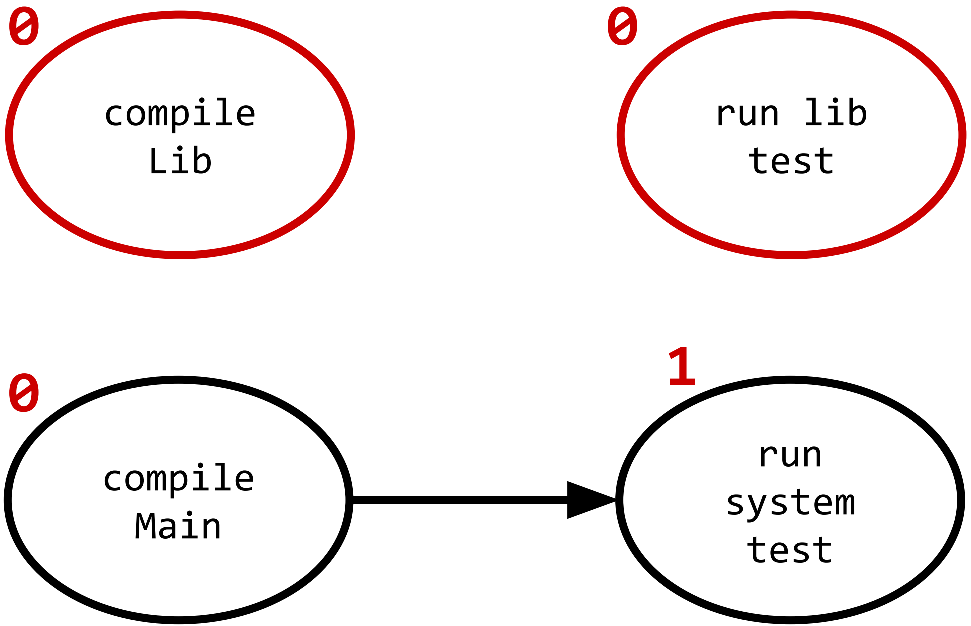

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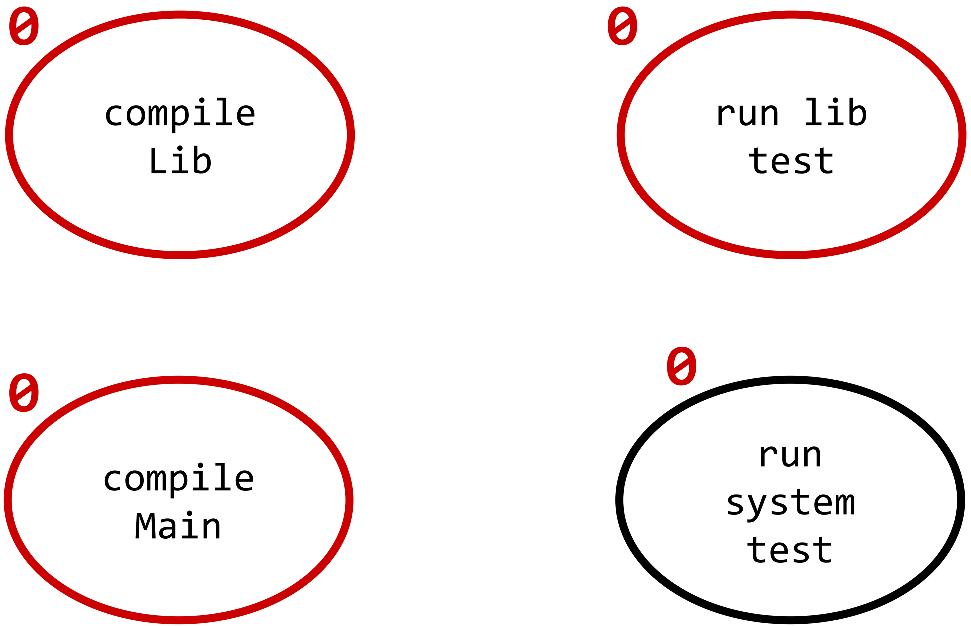

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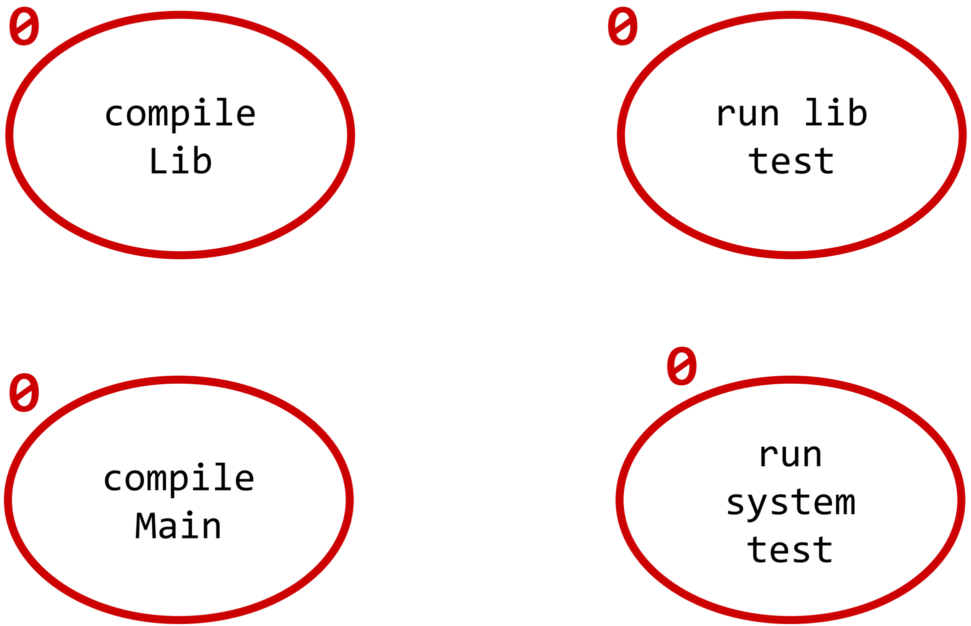
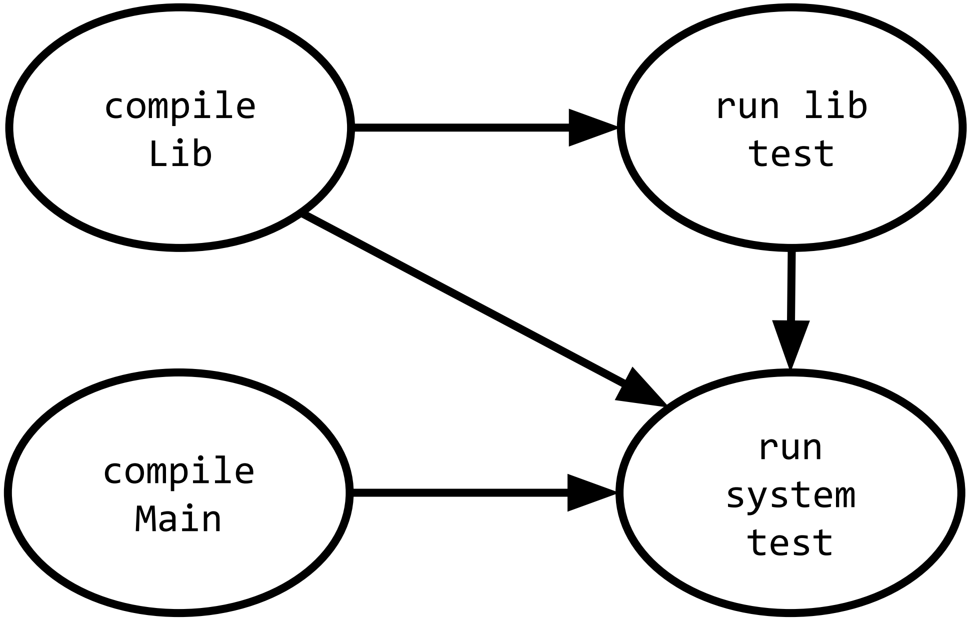


Topological sort

Valid sorts:

1. compile Lib, run lib test, compile Main, run system test



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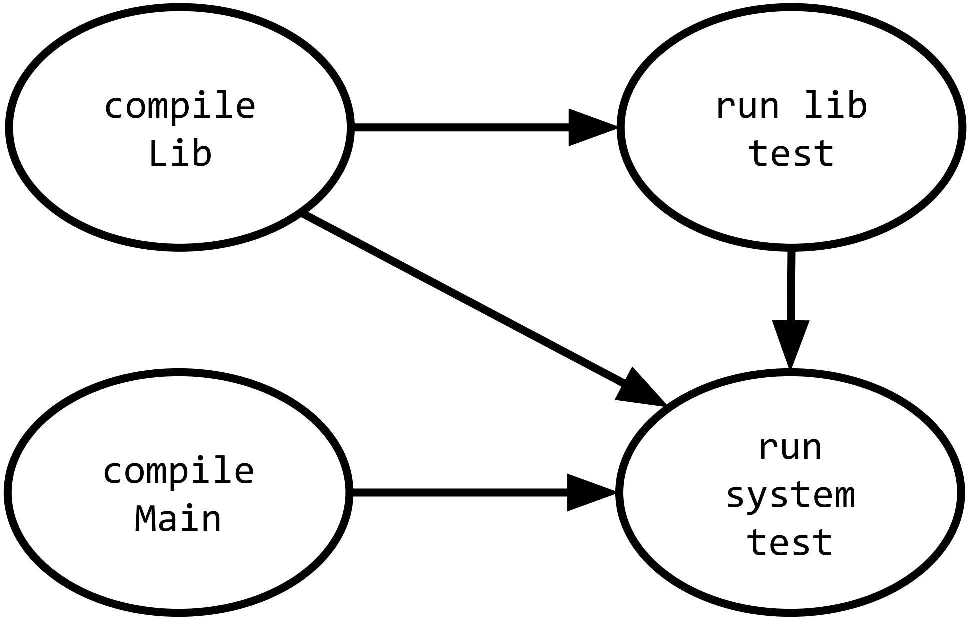

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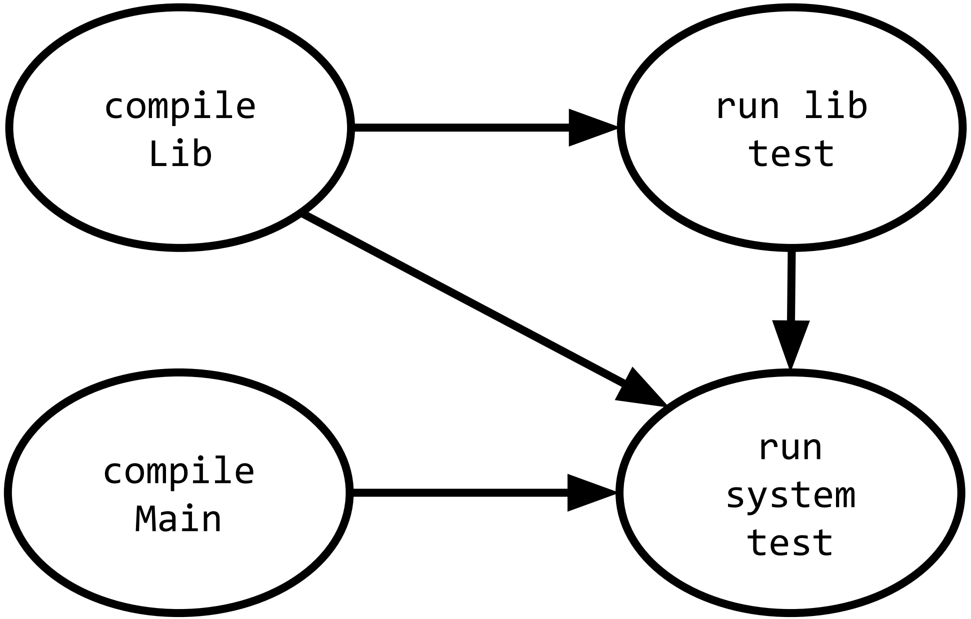

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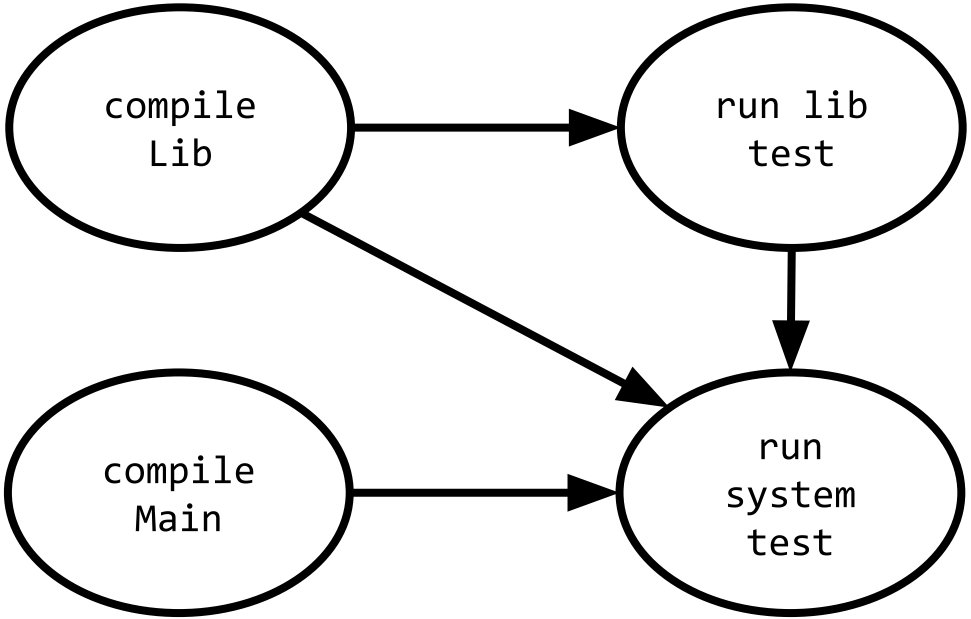

Why is this order silly?

Examples of modern build systems

gradle

https://gradle.org/

Apache's open-source successor to ant, maven

bazel

https://www.bazel.build/

Google's internal build tool, open-sourced

Example task: `gradle`

```
task reformat(type: Exec, dependsOn: getCodeFormatScripts, group: 'Format') {
   description 'Format the Java source code'
   // jdk8 and checker-qual have no source, so skip
   onlyIf { !project.name.is('jdk8') && !project.name.is('checker-qual') }
   executable 'python'
   doFirst {
       args += "${formatScriptsHome}/run-google-java-format.py"
       args += "--aosp" // 4 space indentation
       args += getJavaFilesToFormat(project.name)
   }
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code!

Example task: `bazel`

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java_binary(
    name = "dux",
    main_class = "org.dux.cli.DuxCLI",
    deps = ["@google_options//:compile",
            "@checker_qual//:compile",
            "@google_cloud_storage//:compile",
            "@slf4j//:compile",
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explicitly specified dependencies (also bazel tasks)

External and internal dependencies

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```
dependencies {
    compile group:
        'org.hibernate',
        name: 'hibernate-core',
        version : '3.6.7.Final'
    testCompile group:
        'junit',
        name: 'junit',
        version : '4.+'
}
```

https://docs.gradle.org/current/userguide/artifact_dependencies_tutorial.html

Why list dependencies?

- Reproducibility!

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- ***Hermetic builds***: "they are insensitive to the libraries and other software installed on the build machine"[1]

[1] https://landing.google.com/sre/sre-book/chapters/release-engineering/

Why list dependencies?

- Reproducibility!
- ***Hermetic builds***: "they are insensitive to the libraries and other software installed on the build machine"[1]
    - critical if you want to get new developers working quickly (remember the reading!)
    - useful for debugging problems users encounter with old versions (can always get back to exactly the code they're using)
    - prevents "it works on my machine" syndrome

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Dependencies between tasks

- A large project may have thousands of tasks
  - What order to run in?
  - **How to speed up?**

How to speed up builds?

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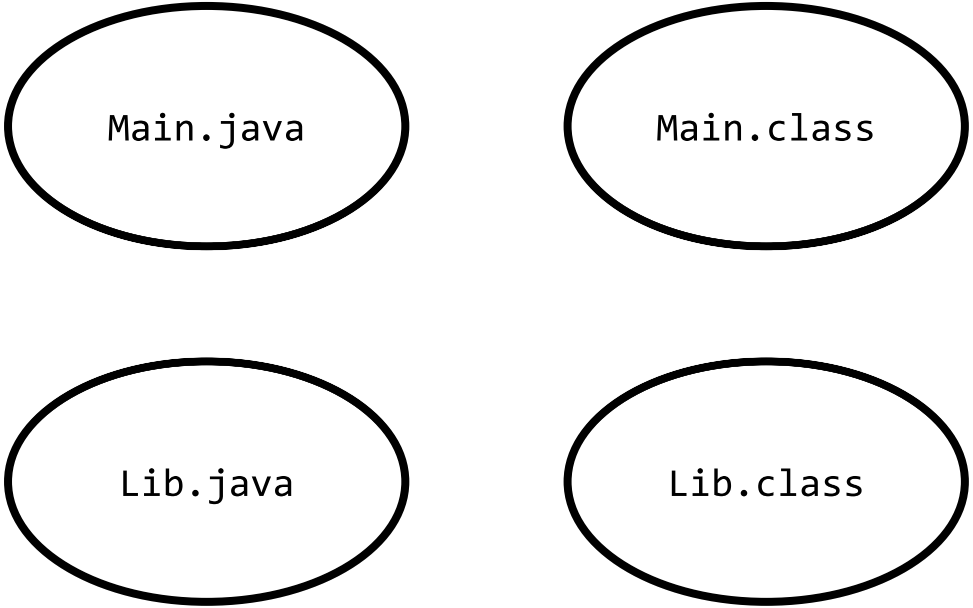
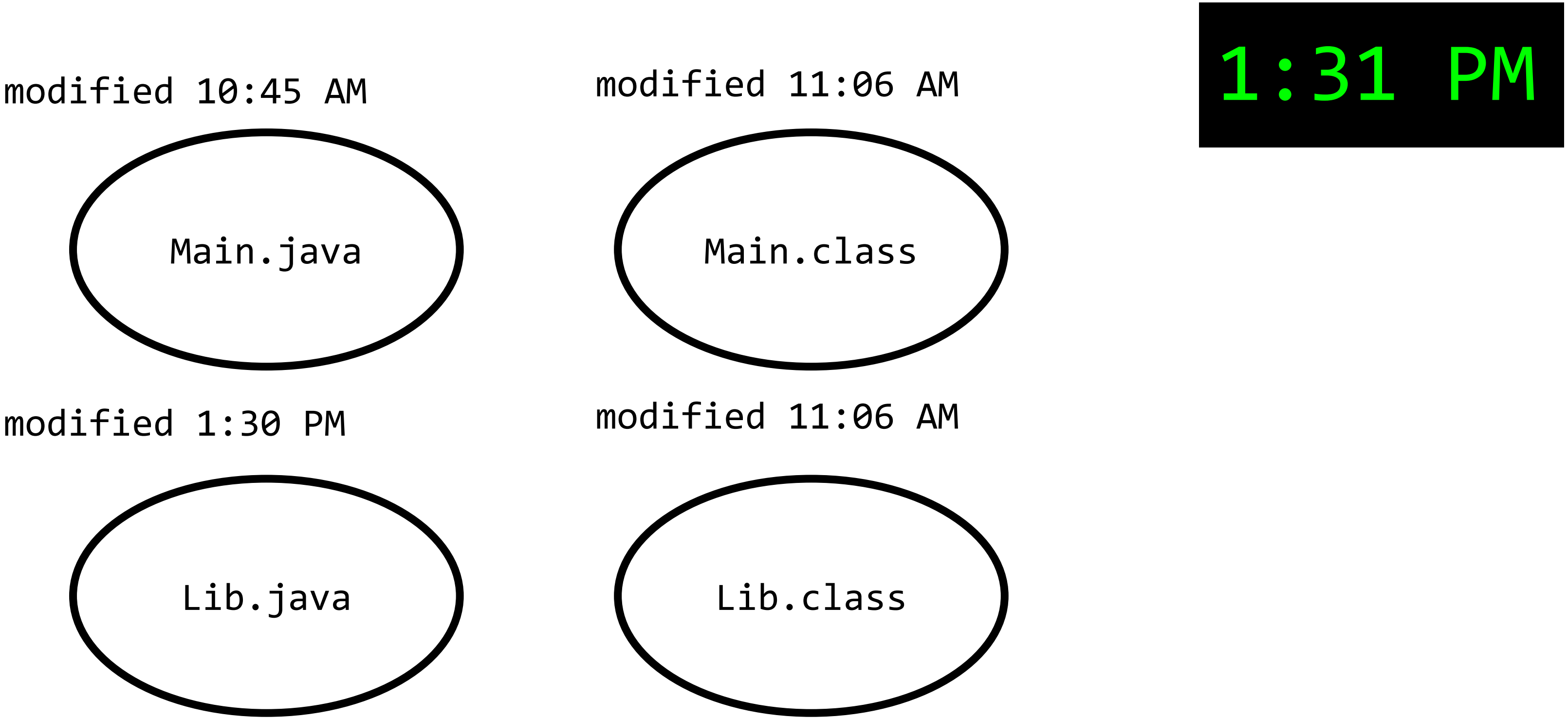
- **Incrementalize** - only rebuild what you have to

Incrementalization



Incrementalization: time stamps



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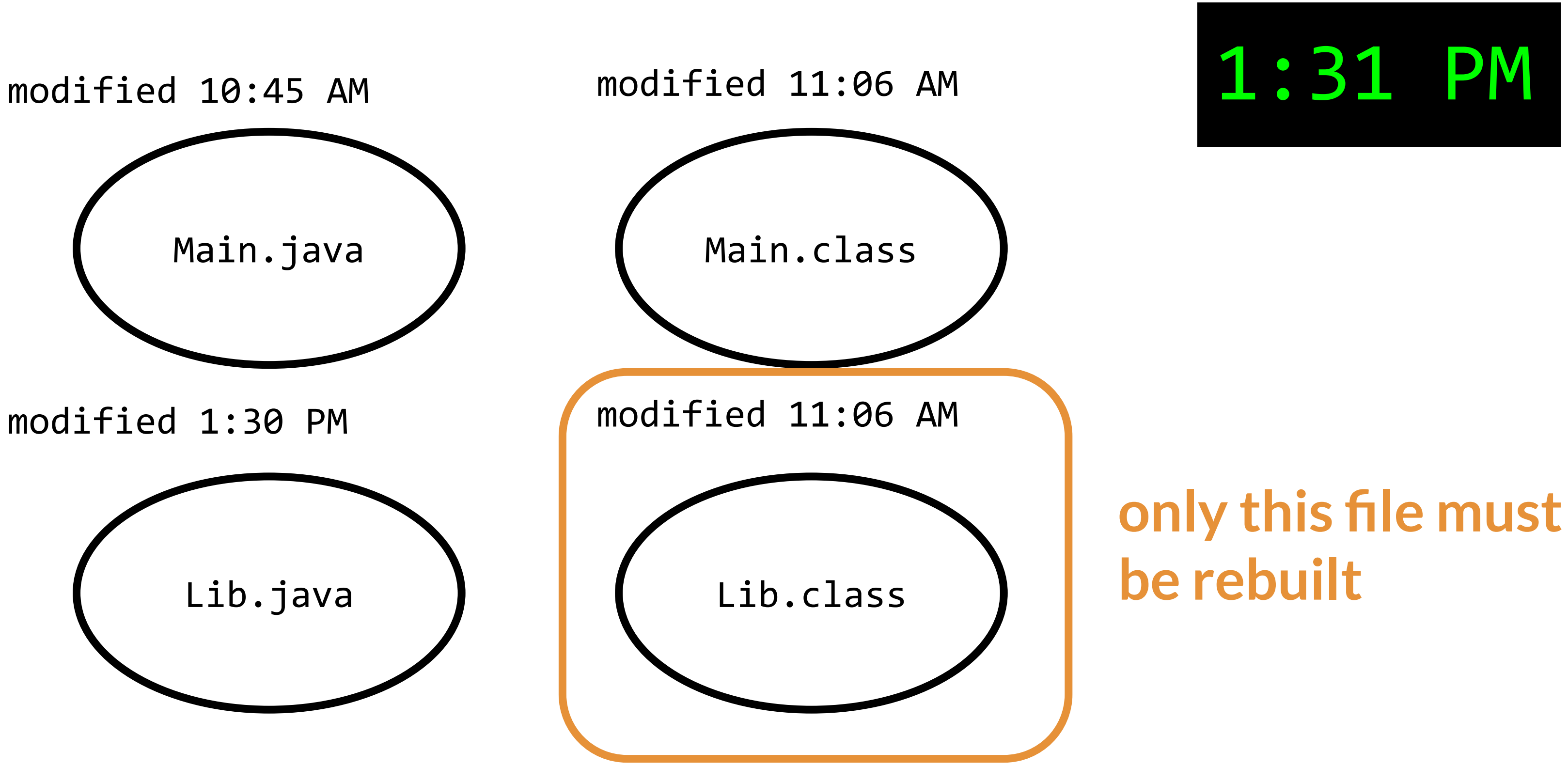

Incrementalization: hashing

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- Compute hash codes for inputs to each task
- When about to execute a task, check input hashes - if they match the last time the task was executed, skip it!

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- **Cache** artifacts in the cloud

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  - **Dynamic** scheduling algorithms are also possible
    - **Key idea**: compute what dependencies are necessary as you go
    - this is how e.g., Bazel actually schedules tasks

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  - We’ve seen two:
    - a ***dirty bit*** strategy (make’s timestamps)
    - a ***verifying trace*** strategy (storing hashes of each object)
  - Other options:
    - ***constructive traces***: store all intermediate objects (usually in the cloud) along with the hashes of the **inputs** used to produce them. If we ever see the same input hashes again, just return the intermediate object

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    - “declarative” = you tell the build system what you want, it figures out how to build that thing
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        - "declarative" = you tell the build system what you want, it figures out how to build that thing
        - call back to last class: programming languages can also be from the ***declarative paradigm*** (e.g., Prolog)
    - most modern build systems have **scripting languages**
        - e.g., Groovy in Gradle, Starlark in Bazel, etc.
        - enables us to write tasks as if they are other code

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High level idea: same rules apply to choosing a language

- **don't change what's already there** unless there is a good reason
- **follow convention** and prefer the tooling that's "idiomatic" to your language
  - e.g., use Gradle or Maven when working in Java

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    - lack of support for artifact caching (= **cloud builds**)
    - build has become too complex for a declarative task language
  - most projects keep the same build system **forever**

Best practices

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> Your CI server is a good place to test that your build is hermetic. **Standard practice**: spin up a new CI server for **each build**.

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A **common mistake to avoid**: allowing the CI server to fail for a long time because “we know what the problem is.” Don’t do this: leads to complacency, missing real bugs.

Reading quiz: build systems

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A. an hour
B. a day
C. a week

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> "A sane software development project has automatic daily builds, performed on a **neutral build server**."

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