Languages + Build Systems

Martin Kellogg

Languages and Build Systems

Today's agenda:

- **Finish slides on Languages**
  - paradigms, type systems, 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

Functional advantages

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- Tractable program semantics
  - Procedures are functions (simplifies reasoning)
  - Formulate and prove assertions about code more easily
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- ***Referential transparency***
  - Replace any expression by its value without changing the result
- “No” side-effects
  - Fewer errors

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Language	Speed	Space
C (gcc)	1.0	1.1
C++ (g++)	1.0	1.6
OCaml	1.5	2.9
Java (JDK -server)	1.7	9.1
Lisp	1.7	11
C# (mono)	2.4	5.6
Python	6.5	3.9
Ruby	16	5.0

17 small benchmarks

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  - New programming style
- Not appropriate for every program
  - Some programs are inherently stateful

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- **extraordinarily common**
- models **the real world** well
    - objects are good abstractions for real-world entities and concepts

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Which of the two does Java use? What about JavaScript?

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
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- **type theory** is the discipline of math (yes!) that studies the formal properties of type systems
- most programming languages include some kind of type system
  - exceptions: assembly, Lisp, a few others

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- **Insight**: typechecking is just another program analysis

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  - Benefits of static typing:
    - early detection of errors, types are documentation
  - Benefits of dynamic typing:
    - faster prototyping, no false positives

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  - stronger types can be added to a language (**ask me more**)
    - “pluggable types”

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Remember: **Don't Repeat Yourself**
If someone else has already built what you need, don't build it again

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- Tied to **language popularity**: languages that are more popular have better libraries, so people are more likely to use them
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- Tied to **language popularity**: languages that are more popular have better libraries, so people are more likely to use them
  - positive feedback loop!
- Common situation: you need library A and library B, but A is written in language L and B is written in language M
  - What to do?

Multi-language projects

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Multi-language projects are common!
Developer quote: ““My last 4 jobs have been apps that called: Java from C#, and C# from F#; Java from Ruby; Python from Tcl, C++ from Python, and C from Tcl; Java from Python, and Java from Scheme (And that's not even counting SQL, JS, OQL, etc.)””

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For example, concurrency might be better handled in F#/OCaml (immutable functional) or Ruby (designed to hide such details), while low-level OS or hardware access is much easier in C or C++, while rapid prototyping is much easier in Python or Lua, etc.

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C/C++ is a lingua franca

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- 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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- Most **tools are language specific**: testing frameworks (+ generation, coverage, etc.), static analysis, build systems, debuggers, etc.

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  - C: good performance, easy-ish to write, very unsafe

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- 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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    - 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**

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- library support
  - the standard library is especially important
- performance
- **team/process factors**
  - how well do you know the language
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  - cf. AWS employs some JVM experts to tune the garbage collector for AWS services that use Java

Team/process factors

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> **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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- Implication: if all else is equal, **choose the more popular** language

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

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- This is usually a **risky thing** to do:
  - you’re not building new features
  - integration problems
  - will the benefits be worth it?

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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

Reading Quiz: Build Systems

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A. shell scripts
B. the IDE
C. developer knowledge
D. testing

Q2: **TRUE** or **FALSE**: the author thinks that the length of time that it takes for you to get a new team member working productively on your project is a good measure of the health of a software project

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Build Systems

Today's agenda:

- Finish slides on Languages
- **What is a build system? How does one work?**
- How to choose a build system + best practices

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- Run static analysis
- Generate documentation
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From the reading

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Key objective of a build system: avoid this problem!

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- Running static analysis
- Generating documentation
- Running tests
- Creating artifacts for customers
- Shipping!

What is a build system?

Definition: A ***build system*** is a tool for orchestrating software engineering tasks

- Getting the source code
- Installing dependencies
- Compiling the code
- Running static analysis
- Generating documentation
- Running tests
- Creating artifacts for customers
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A good build system handles all these

Tasks

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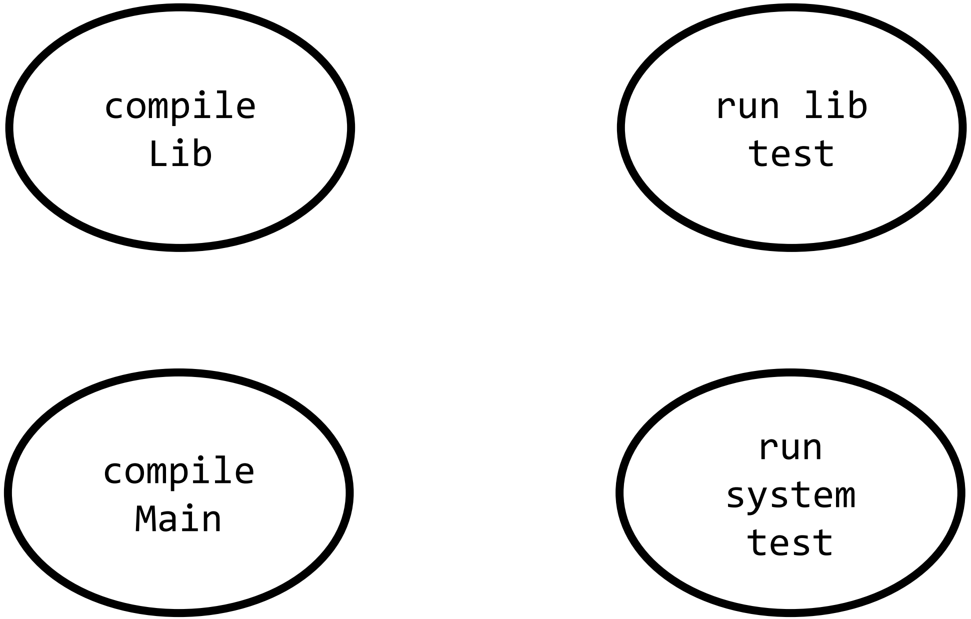
- Tasks also commonly have **dependencies**
  - Dependency management is a key build system responsibility!

Dependencies between tasks

```
> ls src/

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

Dependencies between tasks



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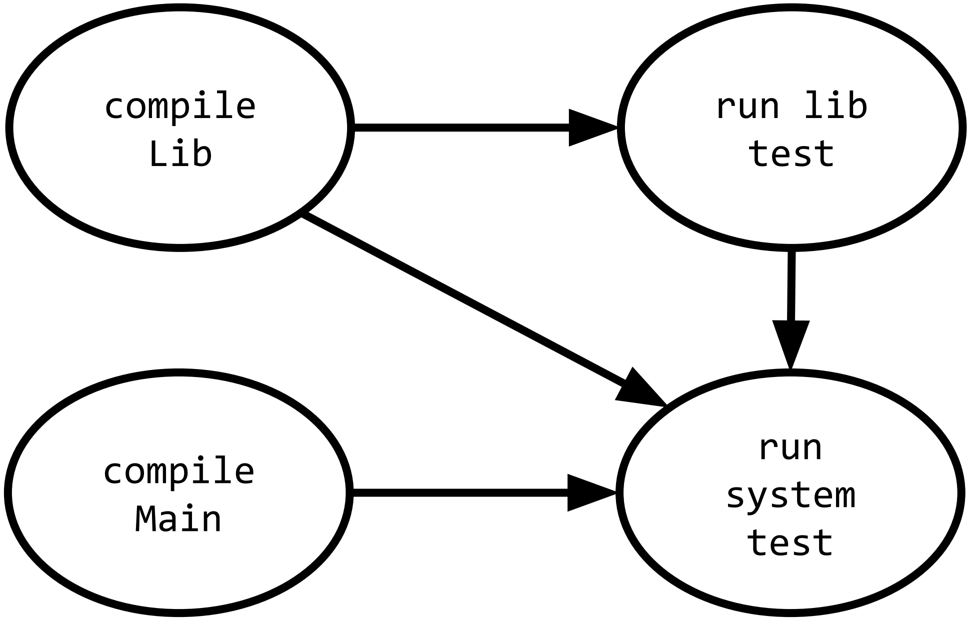

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Topological sort!

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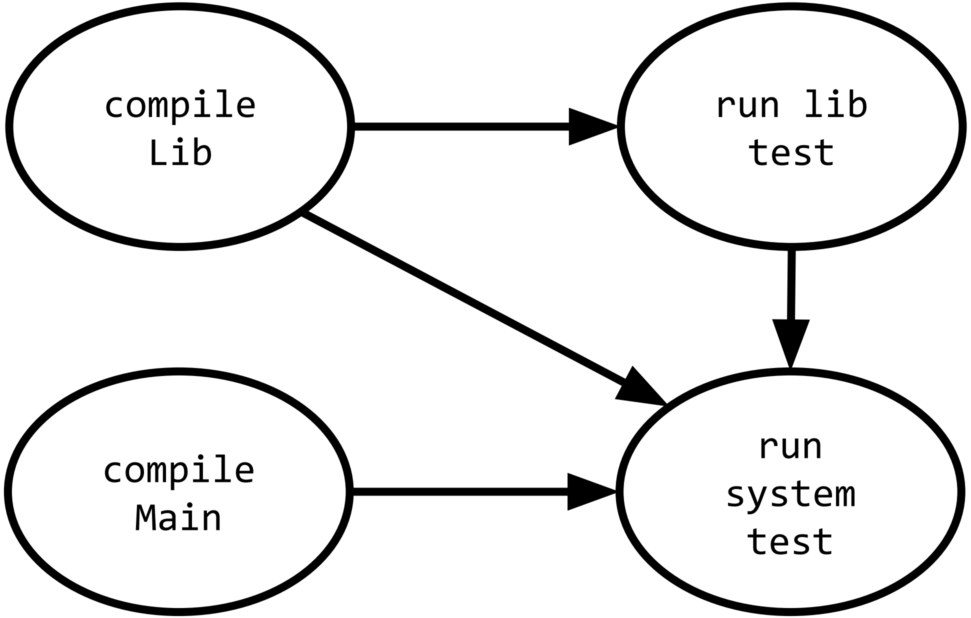
- Implement by computing ***indegree*** (number of incoming edges) for each node

Topological sort



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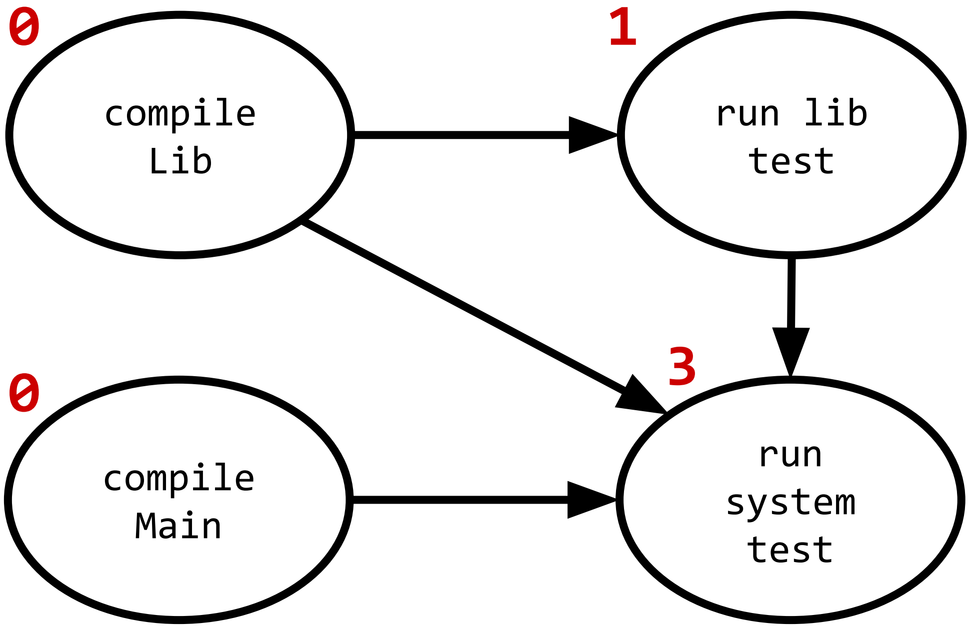

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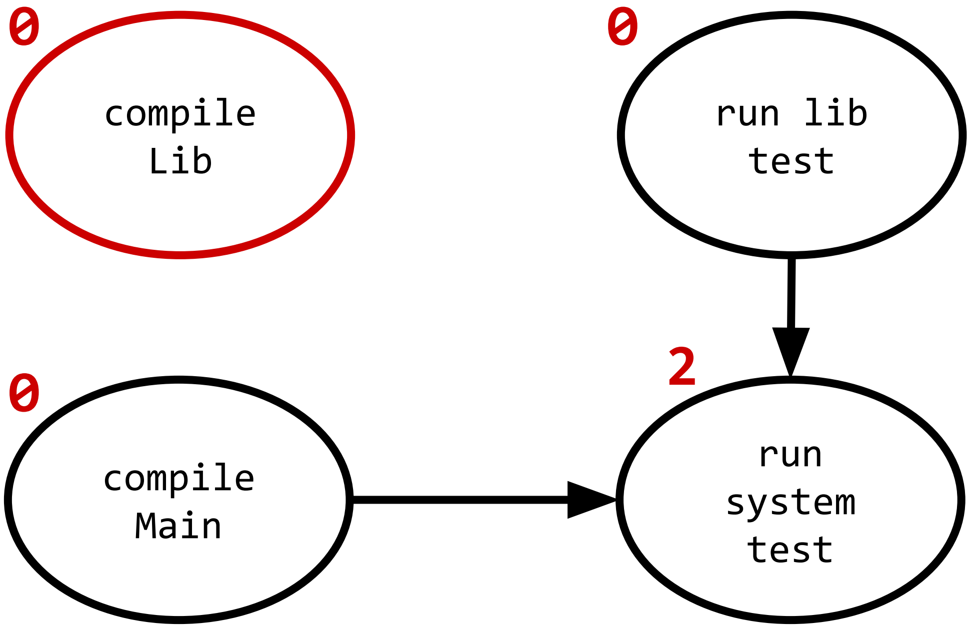

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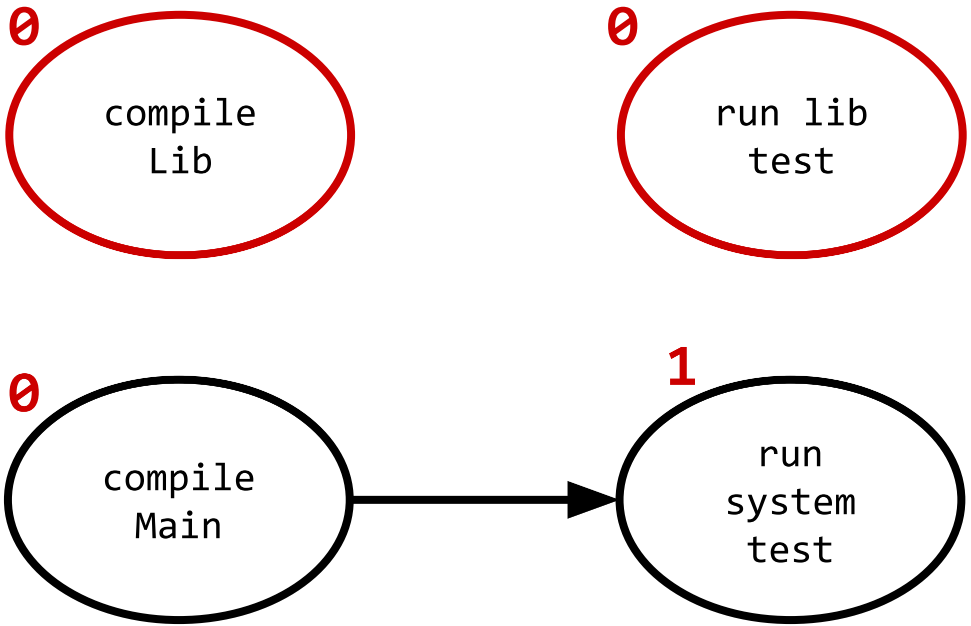

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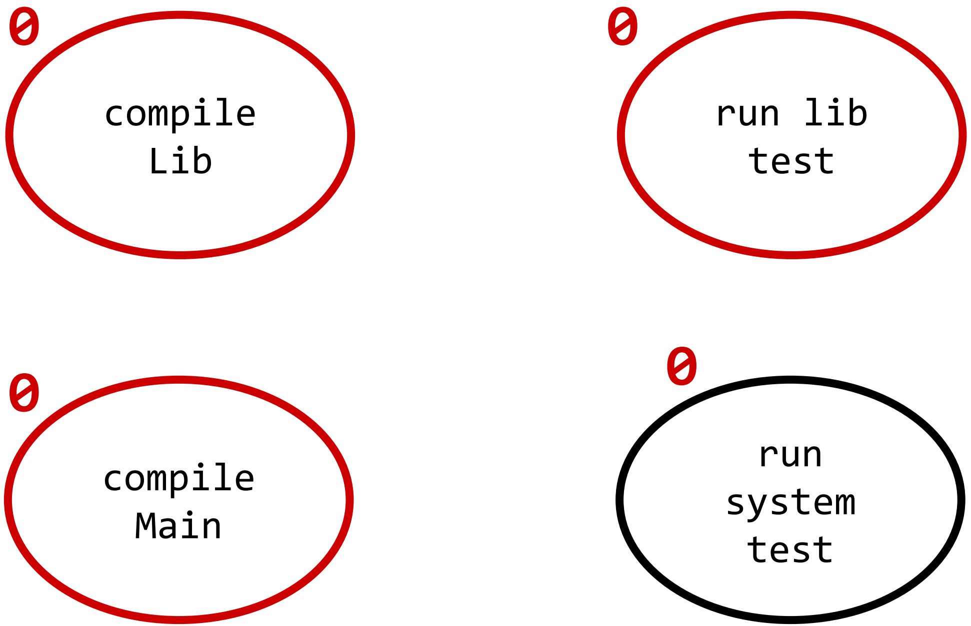

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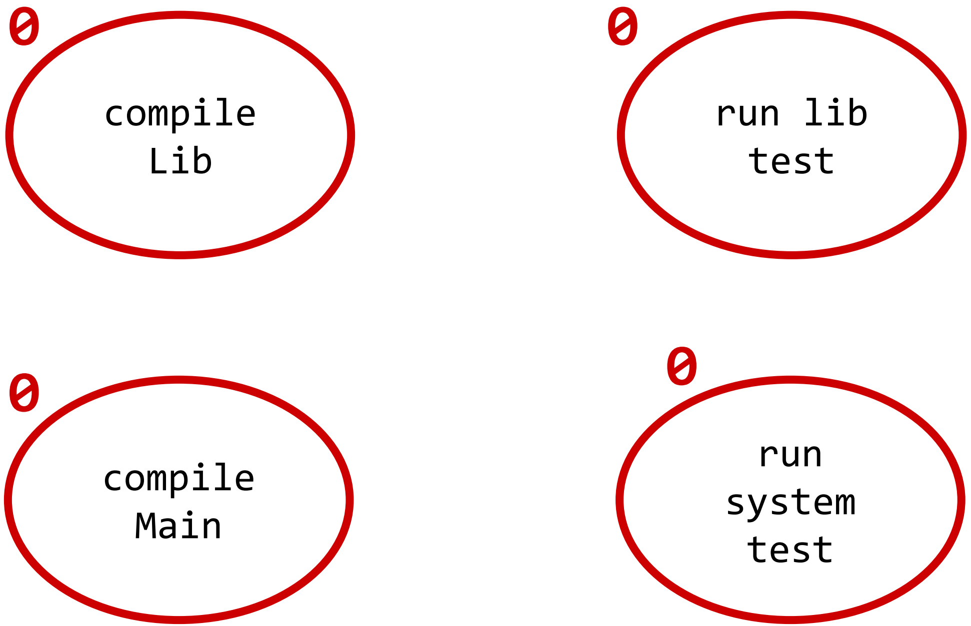
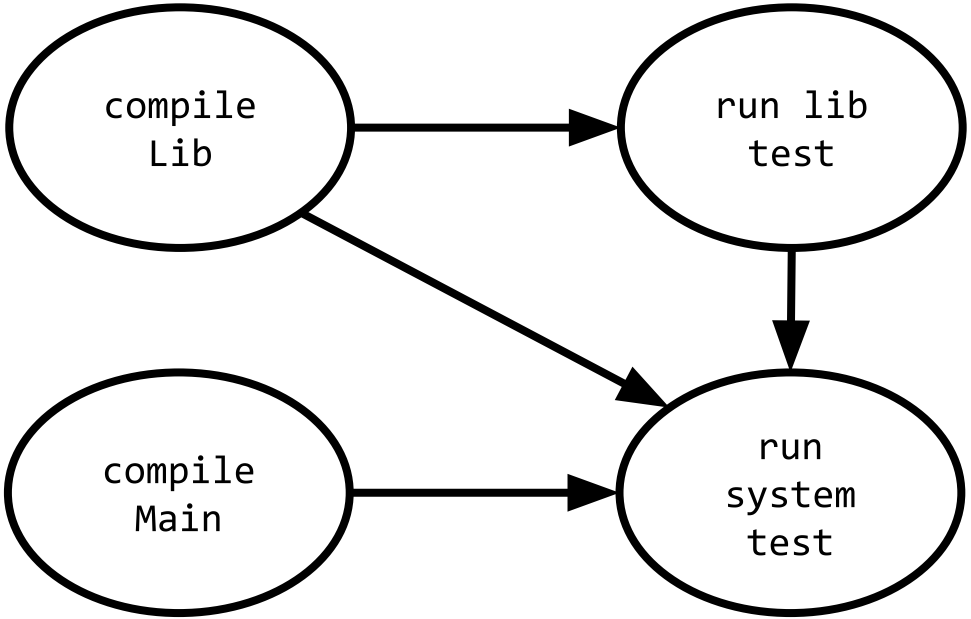


Topological sort

Valid sorts:

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



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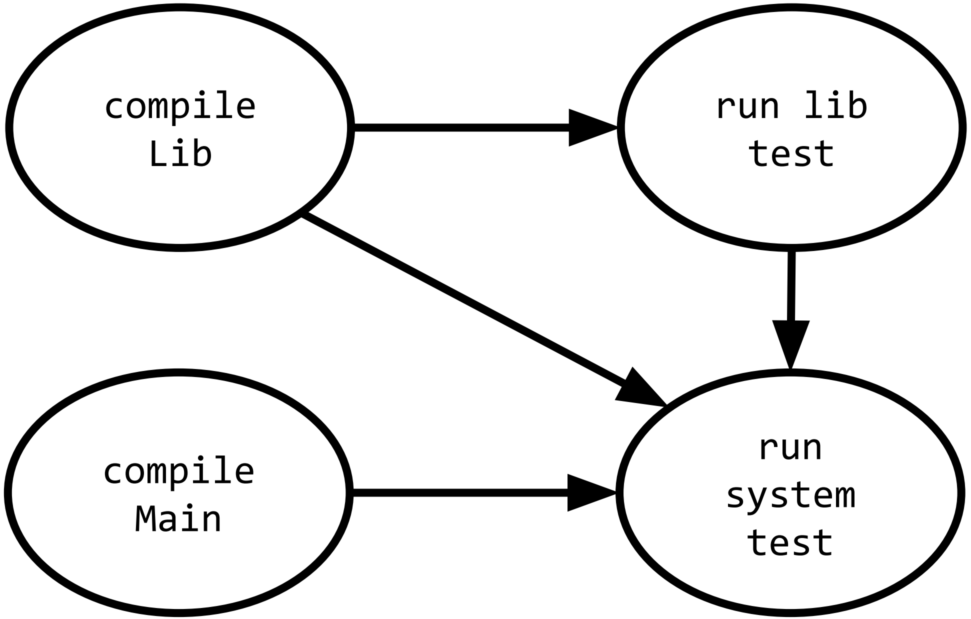

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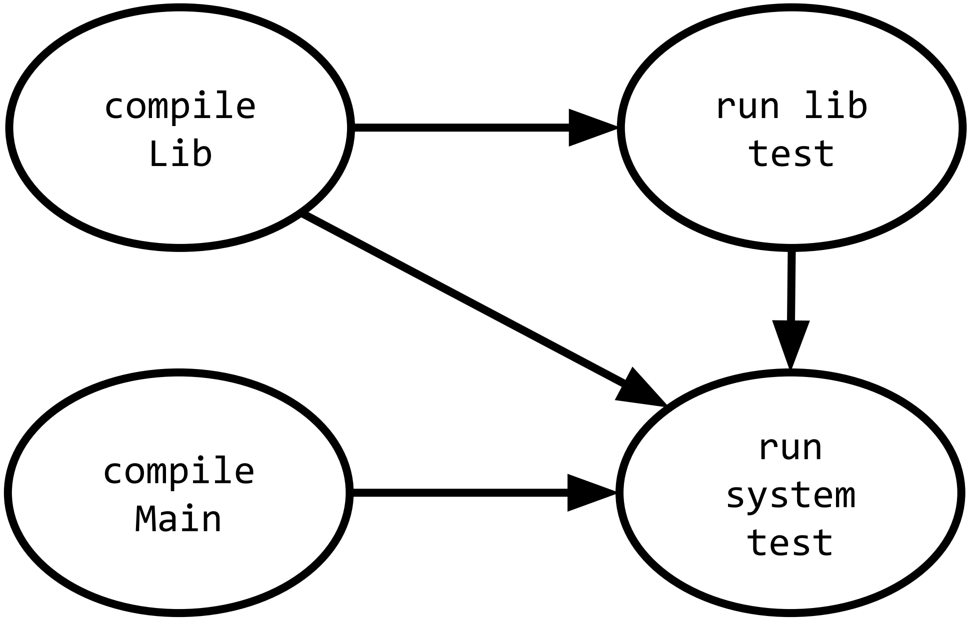

Examples of modern build systems

`gradle`

https://gradle.org/

Apache's open-source successor to ant, maven

`bazel`

https://www.bazel.build/

Google's internal build tool, now open-source

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"
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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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    srcs = glob(["src/org/dux/cli/*.java",
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explicitly specified dependencies (also bazel tasks)

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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

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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

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  - What order to run in?
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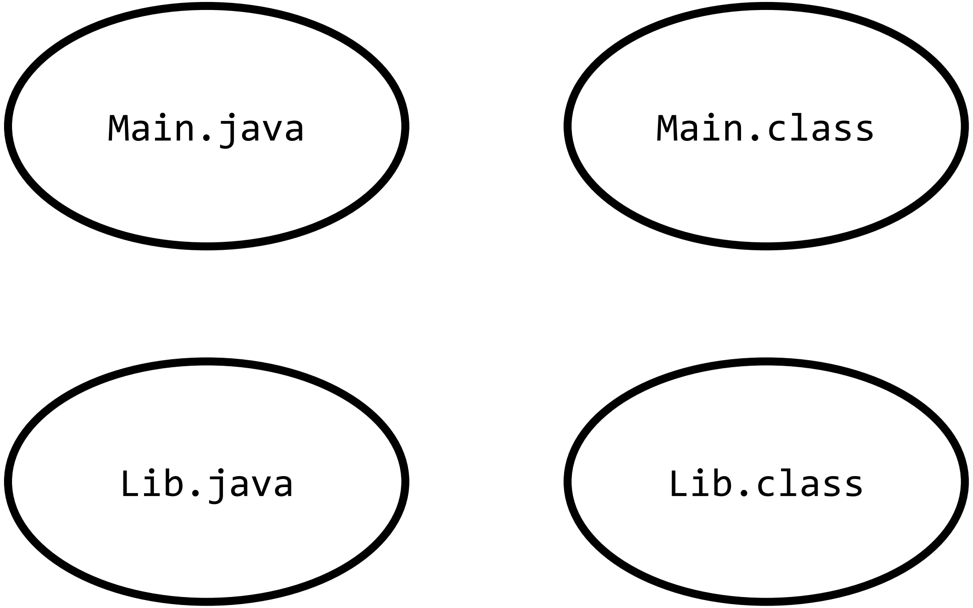
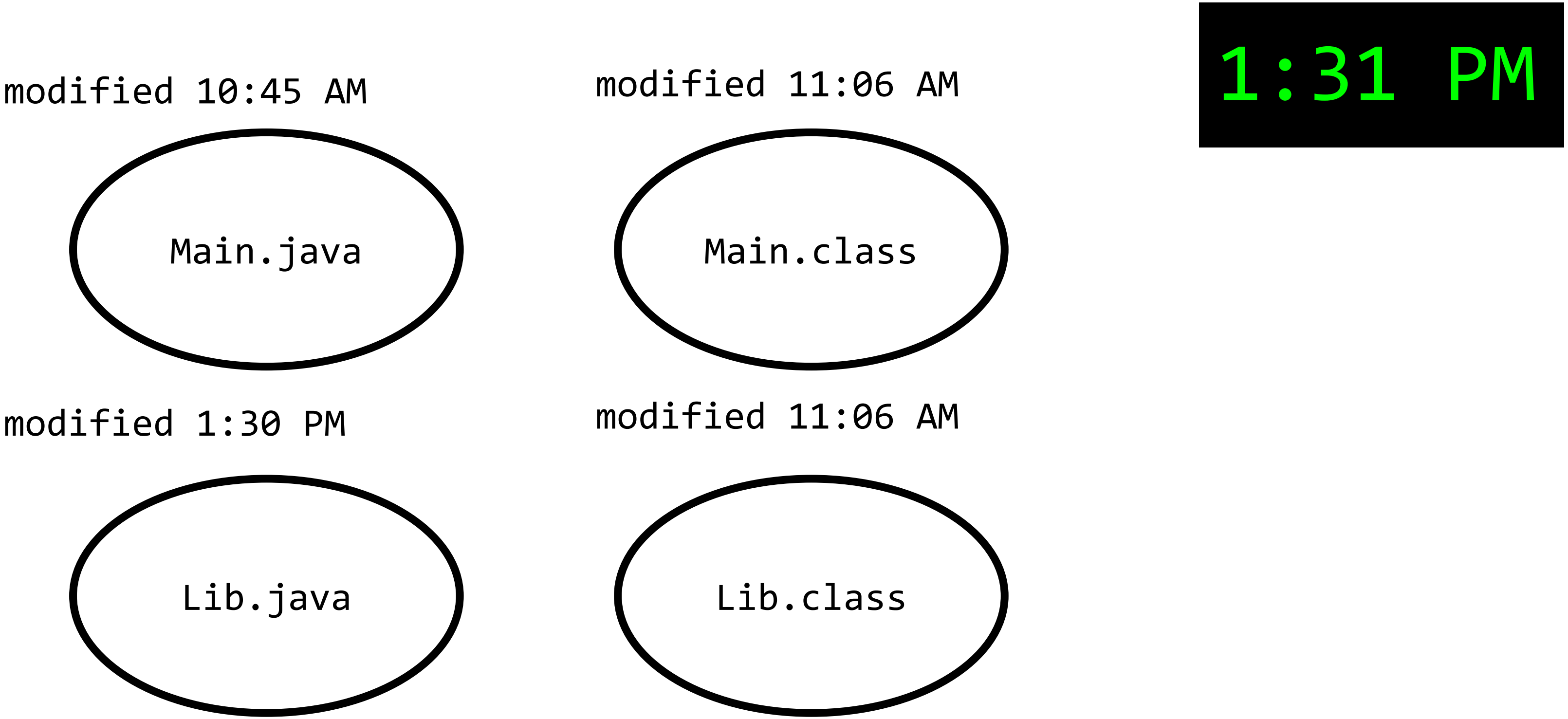
How to speed up builds?

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

Incrementalization



Incrementalization: time stamps



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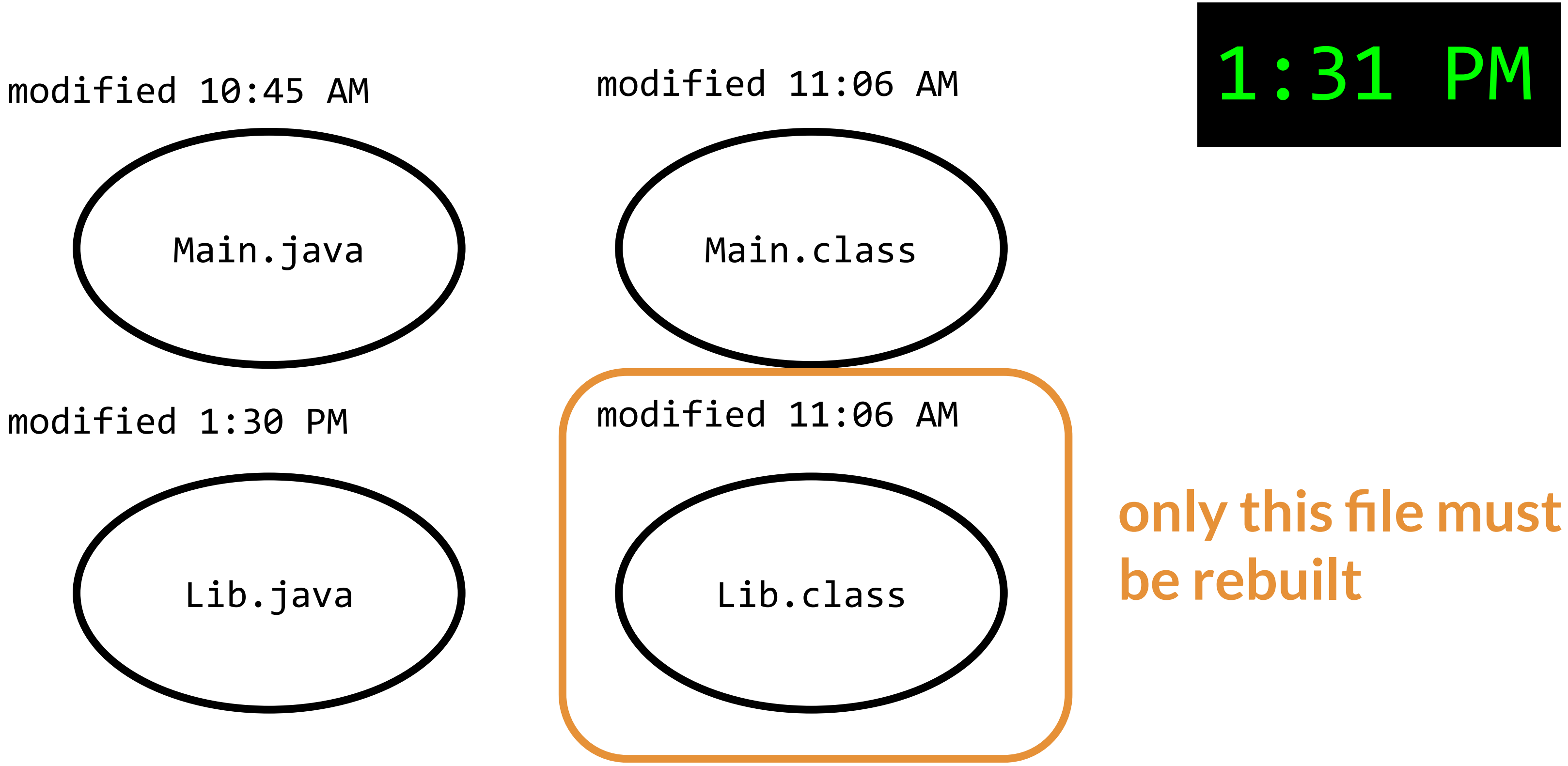

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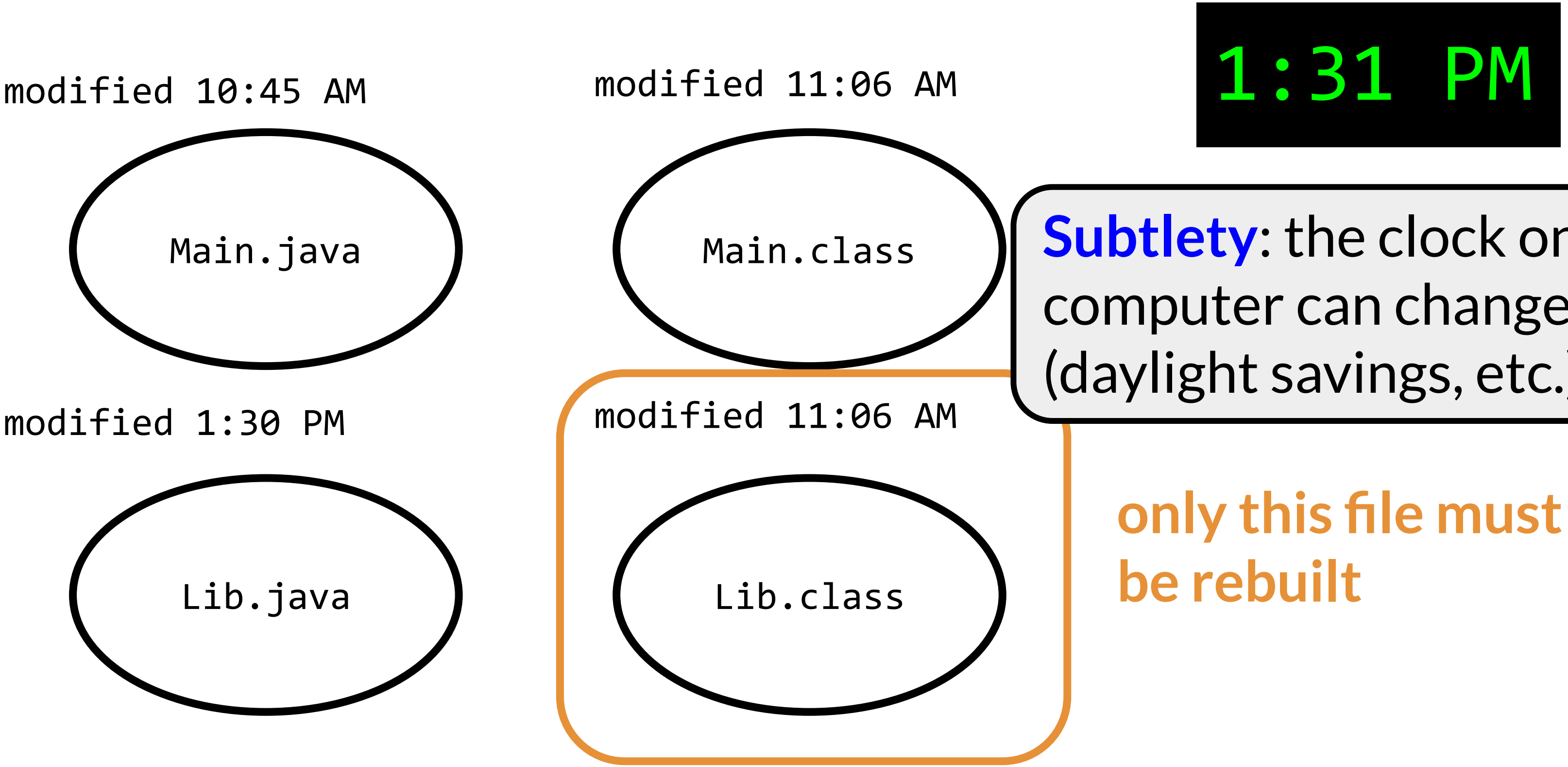

Subtlety: the clock on a computer can change… (daylight savings, etc.)

only this file must be rebuilt

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

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    - 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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    - call back to languages: 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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- **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**

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Best practices

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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- Don't break the build

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.