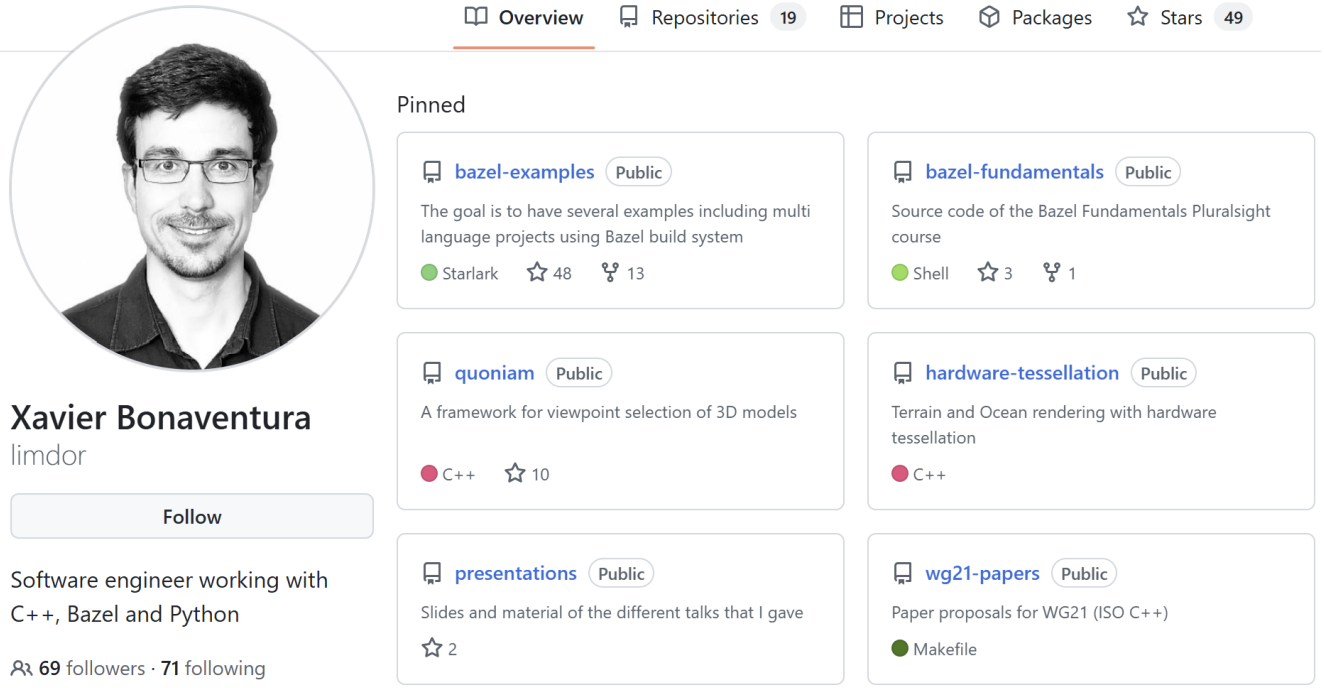
INTRODUCTION TO BAZEL

Xavier Bonaventura

ABOUT ME

- Software developer at BMW Group since 2018
- Working with Bazel for around 7 years
- Multiple contributions to Bazel
- Mainly working on C++ and Python
- Where to find me
  - @limdor
  - @xbonaventurab
  - @xavierbonaventura



ABOUT BAZEL

- What is Bazel?
  - A build system, not a build generator (invokes directly the compiler)
  - With full of functionality for testing (test reports, flaky tests handling, etc.)
  - Bazel core is written in Java, rules and macros written in Starlark

- History From Blaze to Bazel
  - Blaze is the build system at Google (development started around 2007)
  - Part of Blaze was open sourced on 2015 as Bazel
  - It moved from beta to general availability in October 2019
  - Better way to deal with external dependencies since 2022 (Bzlmod)
  - Languages originally embedded into Bazel, they are being moved out since 2024 (Starlarkification)

https://bazel.build

ABOUT BAZEL

- Release process
  - Since the general availability release, Bazel follows semantic versioning
  - Rolling releases every ~2 weeks based on GitHub HEAD
  - Long Term Support (LTS) since Bazel 4.0 (December 2020), a new major LTS release provided every 12 months
  - After a major LTS release, the old version goes into maintenance mode for 2 years
    - https://bazel.build/release
  - Current version is Bazel 8

LTS release	Support stage	Latest version	End of support
Bazel 9	Rolling	Check rolling release page	N/A
Bazel 8	Active	8.3.1	December 2027
Bazel 7	Maintenance	7.6.1	Dec 2026
Bazel 6	Maintenance	6.5.0	Dec 2025
Bazel 5	Deprecated	5.4.1	Jan 2025
Bazel 4	Deprecated	4.2.4	Jan 2024

https://bazel.build/release

BAZEL FEATURES

- Fast and correct
  - Incremental builds and test execution
  - Parallel execution
  - Local and remote cache
  - Hermetic builds thanks to sandboxing
- Multi language, multi platform
  - Java, C/C++, Android, iOS, Go, Python, Rust, etc.
  - Linux, Windows, and macOS

https://bazel.build/about/why

BAZEL FEATURES

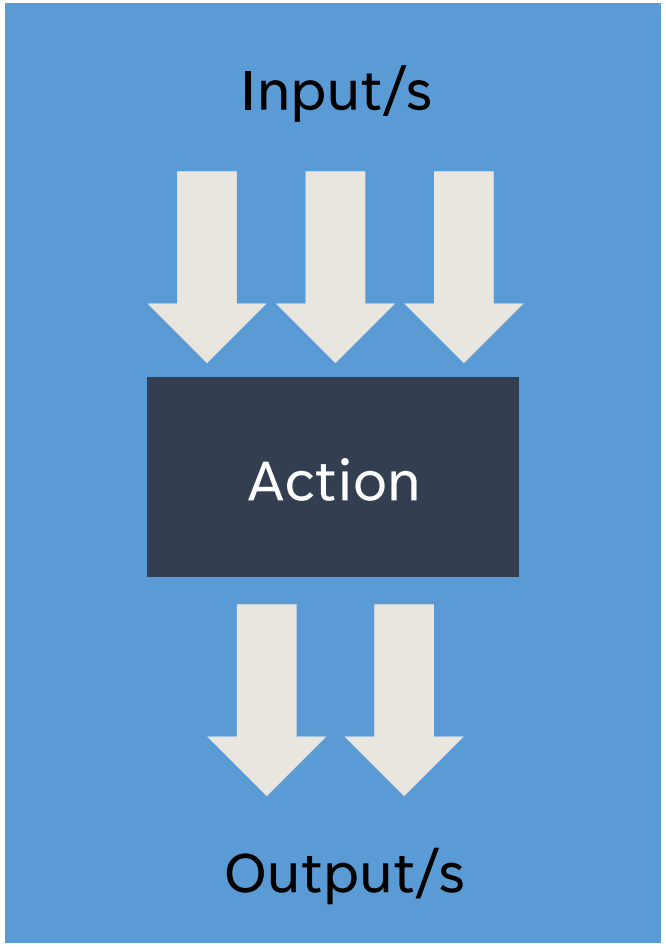
- Scalable
  - It can handle codebases of any size
  - Multiple repositories or huge monorepo, it handles both

- Extensible
  - If a platform or language is not supported can be easily added
  - Extensions are written in Starlark, a language similar to Python

https://bazel.build/about/why

BAZEL IN A NUTSHELL

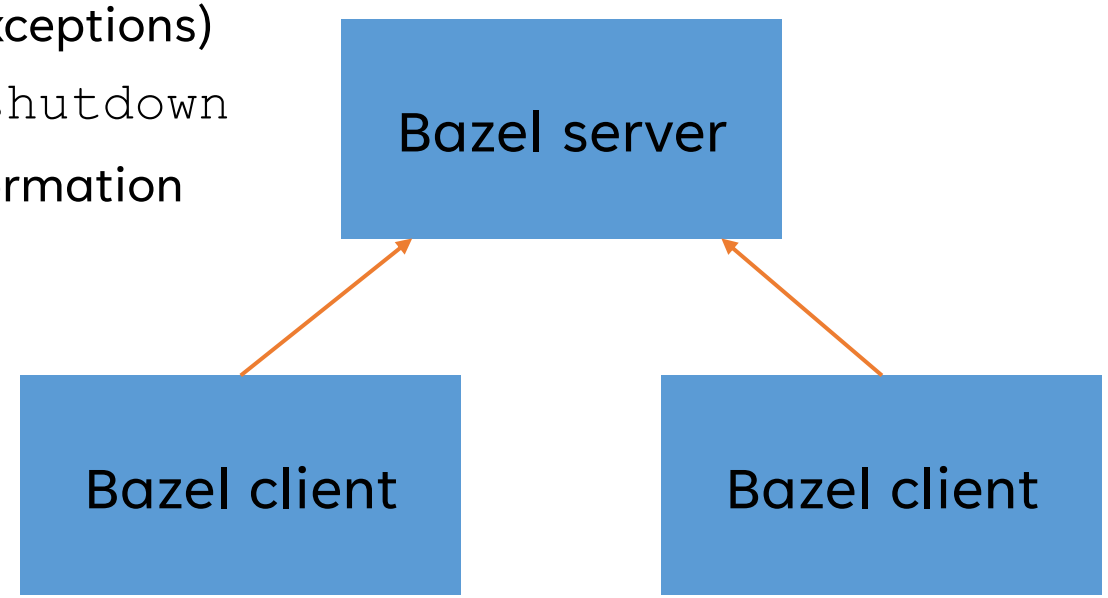
- It is an artifact-based system
  - Inputs are treated as artifacts
  - Outputs are treated as artifacts
  - Actions are treated as artifacts as well
  - For every artifact, a hash is computed in advance to allow caching
- Each action runs on a sandbox
  - Improving reproducibility
  - Better detection of undeclared dependencies
- Composability
  - Outputs of an action can be used as inputs of another action
  - An action can be the output of another action



https://bazel.build/basics/artifact-based-builds

BAZEL DESIGN

- Client/server architecture
  - The first time a Bazel command is executed, a Bazel server is started
  - After the Bazel command finishes, the server keeps running
  - The following commands executed use the already running server
  - Two Bazel clients cannot run in parallel (with exceptions)
  - The Bazel server can be stopped with `bazel shutdown`
  - This architecture allows the server to cache information



https://bazel.build/run/client-server

BAZEL WITH DIFFERENT MODES

- WORKSPACE mode
  - [illegible] 6
  - [illegible] 7
  - external dependencies

Not covered in this talk

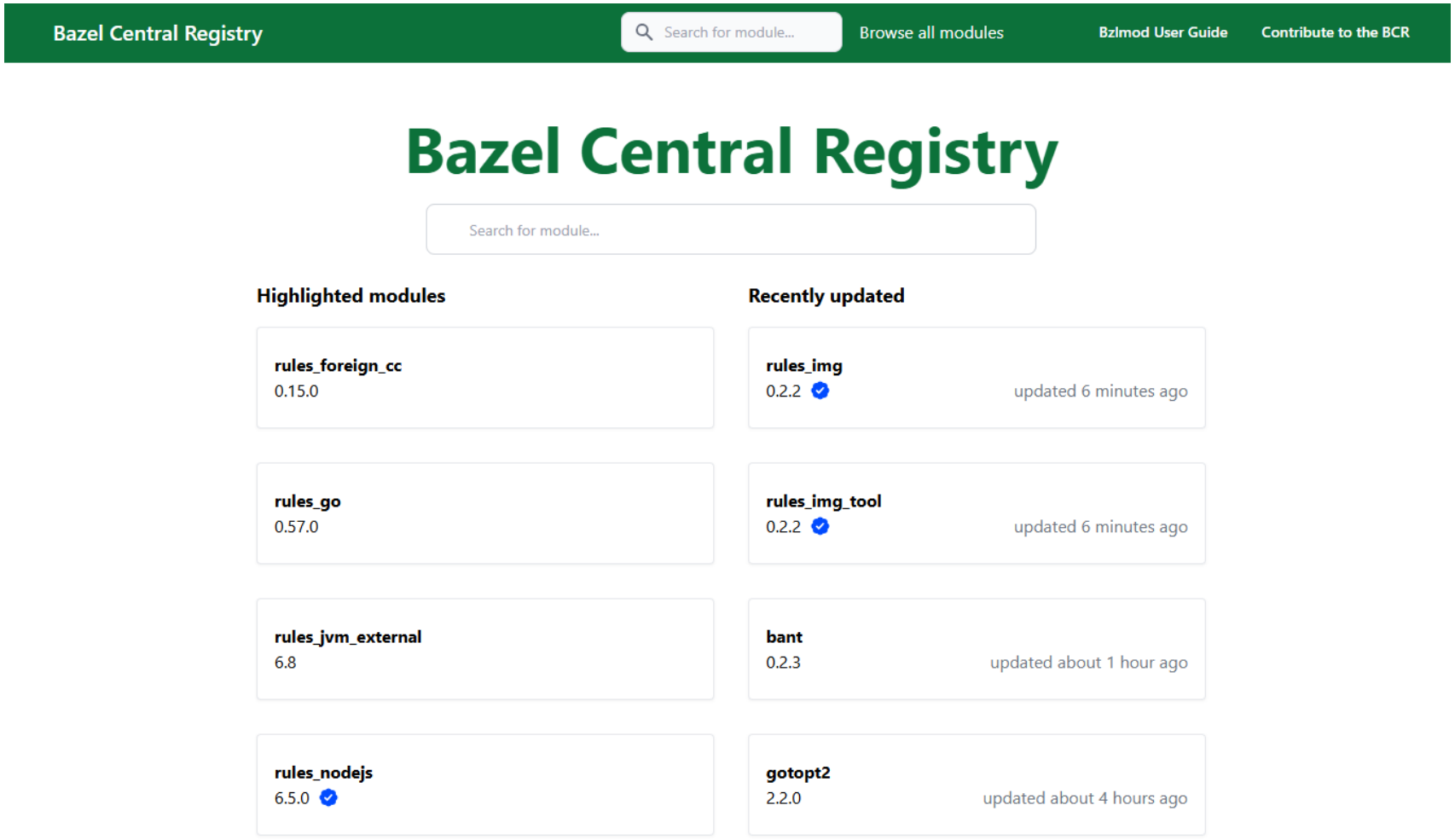
- Bzlmod mode
  - Experimental in Bazel 6, ready to use in Bazel 7
  - Default mode in Bazel 8
  - Only mode starting with Bazel 9
  - Automatic resolution of transitive dependencies

- Hybrid mode
  - Default mode in Bazel 7
  - [illegible] it unless you really need it

Not covered in this talk

https://bazel.build/external/overview

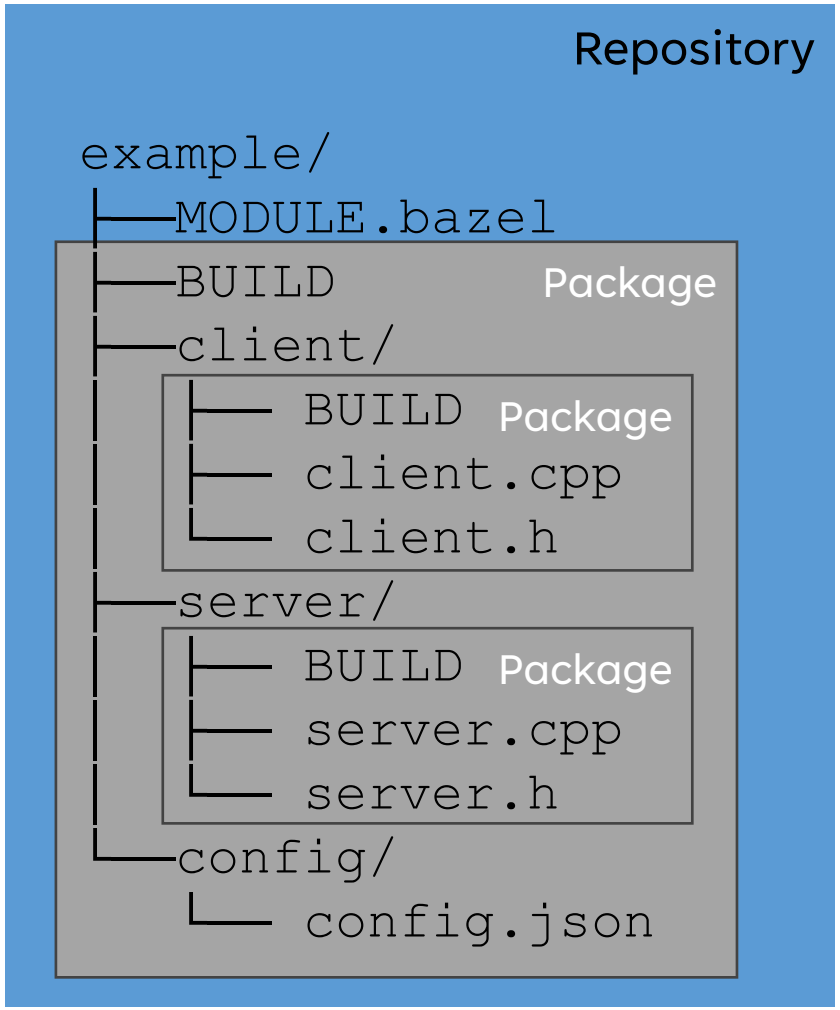
BAZEL CENTRAL REGISTRY



https://registry.bazel.build/

BAZEL FILES

- MODULE.bazel
  - At the root of the source code that you want to build
  - It can be empty
  - Used to declare toolchains and external dependencies
- BUILD
  - At the root of a package
  - A package is defined by all files, folders, and subfolders at the same level like the BUILD file except the ones that contain a BUILD file
  - Where targets are defined
- bzl
  - Used to define Bazel extensions
  - They can be loaded in a BUILD file using the load statement



https://bazel.build/concepts/build-files

BAZEL TARGETS

```
cc_binary(
    name = "foo",
    srcs = ["foo.cpp"],
    deps = [":bar"],
    visibility = ["//visibility:public"],
    tags = ["unit", "fancy"]
)
```

Rule that you want to instantiate

Target name

Sources

Direct dependencies to other targets

What targets can depend on this target

Tags, some might have special meaning

https://bazel.build/concepts/build-ref#targets

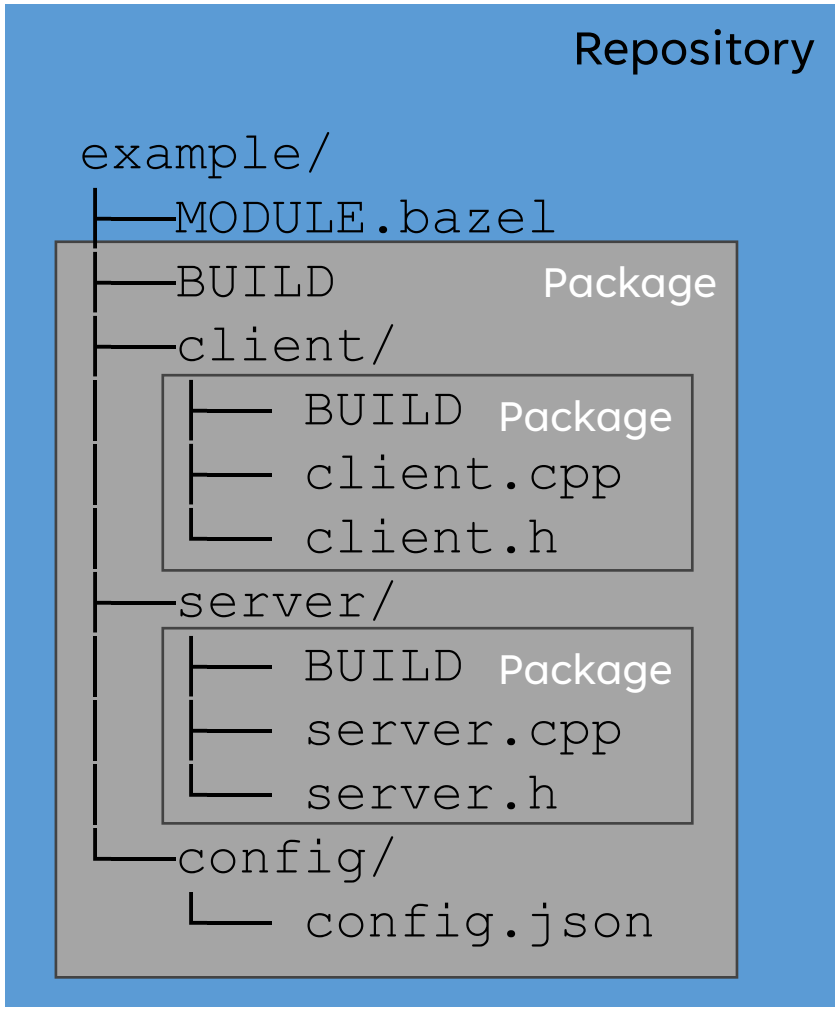
BAZEL LABELS

`@@repository//folder/subfolder:my_target`

- Omitting the repository assumes the current repository:
  `@@repository//folder/subfolder:my_target`
  `//folder/subfolder:my_target`

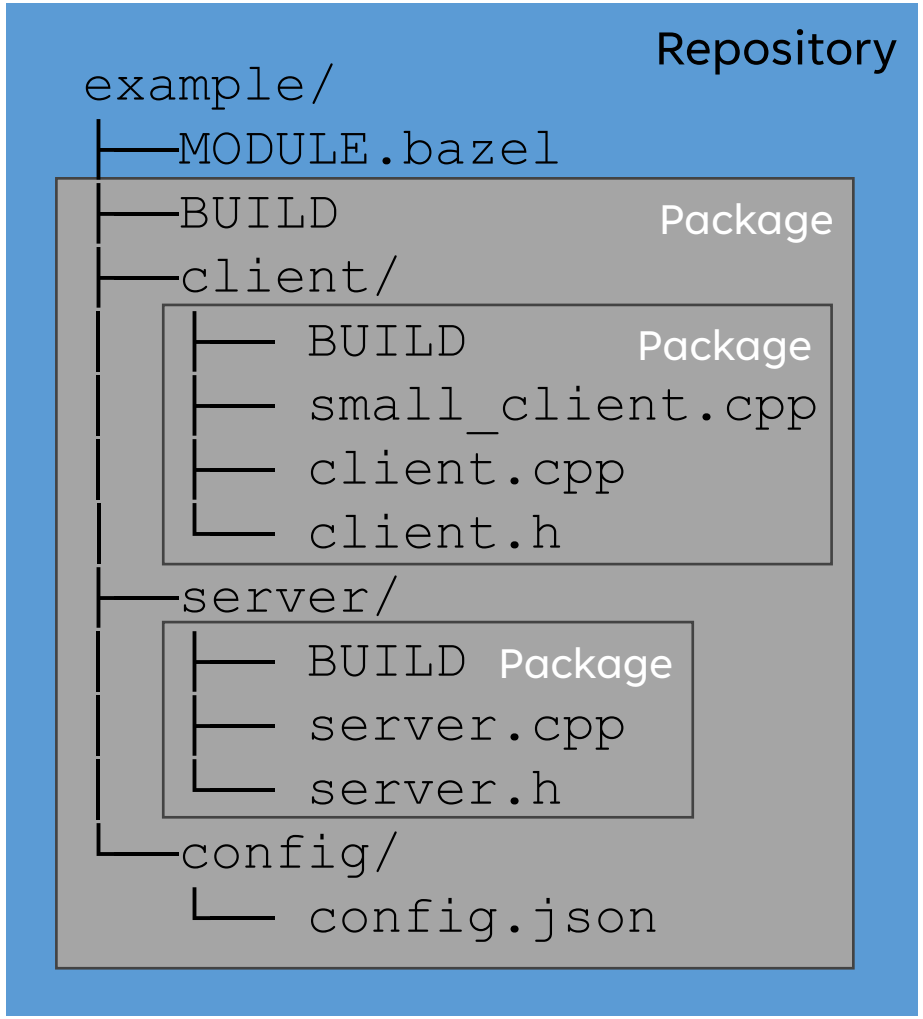
- Omitting the colon assumes the same name as the folder:
  `//lib:lib`
  `//lib`

- Starting with colon search for lib in the same BUILD file
  `:lib`



https://bazel.build/concepts/labels

BAZEL LABELS



- From the same or another file:
  `@@example//client:small_client`
  `//client:small_client`

  `@@example//client:client`
  `@@example//client`
  `//client:client`
  `//client`

- From the same BUILD file:
  `:client`
  `:small_client`

example/client/BUILD

```
...
cc_library(
  name ="small_client",
  ...
)
cc_library(
  name ="client",
  ...
)
```

https://bazel.build/concepts/labels

TARGET VISIBILITY

```
cc_library(
  name = "my_lib",
  srcs = "my_lib.cpp",
  visibility = [
    "//client:__subpackages__",
  ],
  hdrs = ["my_lib.h"],
)
```

- Private: Visible only from the same BUILD file
  `//visibility:private`
- Public: Anyone can see this target
  `//visibility:public`
- Visible by a specific package and subpackages
  `//foo/bar:__subpackages__`
- Visible by a specific package but not subpackages
  `//foo/bar:__pkg__`
- Visibility can be defined per package, per target or both
- By default, the target visibility is the same as the package
- If visibility is not defined, a target is only visible within the BUILD file

https://bazel.build/concepts/visibility

PHASES OF A BUILD

- Loading phase
  - Load extensions, BULD files, transitive dependencies
  - Duration: Several seconds the first time, faster afterwards thanks to caching
- Analysis phase
  - Semantic analysis of each rule
  - Building of the dependency graph
  - Analyze what work needs to be done
  - Duration: Several seconds the first time, faster afterwards thanks to caching
- Execution phase
  - Targets are built: compilation, linking, etc.
  - Execution of targets, tests running, etc.
  - Duration: Most of the time is spend in the execution phase, also can be speeded up thanks to caching

https://bazel.build/extending/concepts#evaluation-model

BAZEL CACHE

- Bazel provides four different levels of cache
  - In memory cache (Bazel server)
    - Lost/cleaned once the Bazel server is stopped
  - Output directory (bazel out)
    - Local to the workspace
    - Can be removed with `bazel clean` and `bazel clean --expunge`
  - Disk cache (folder in local machine)
    - Useful to share artifacts when switching branches
    - Useful if you have multiple workspaces/checkouts of the same project
    - It can make your disk usage grow a lot
  - Remote cache (HTTP/1.1 server)
    - Useful to share artifacts between team members or with the CI

https://bazel.build/remote/caching

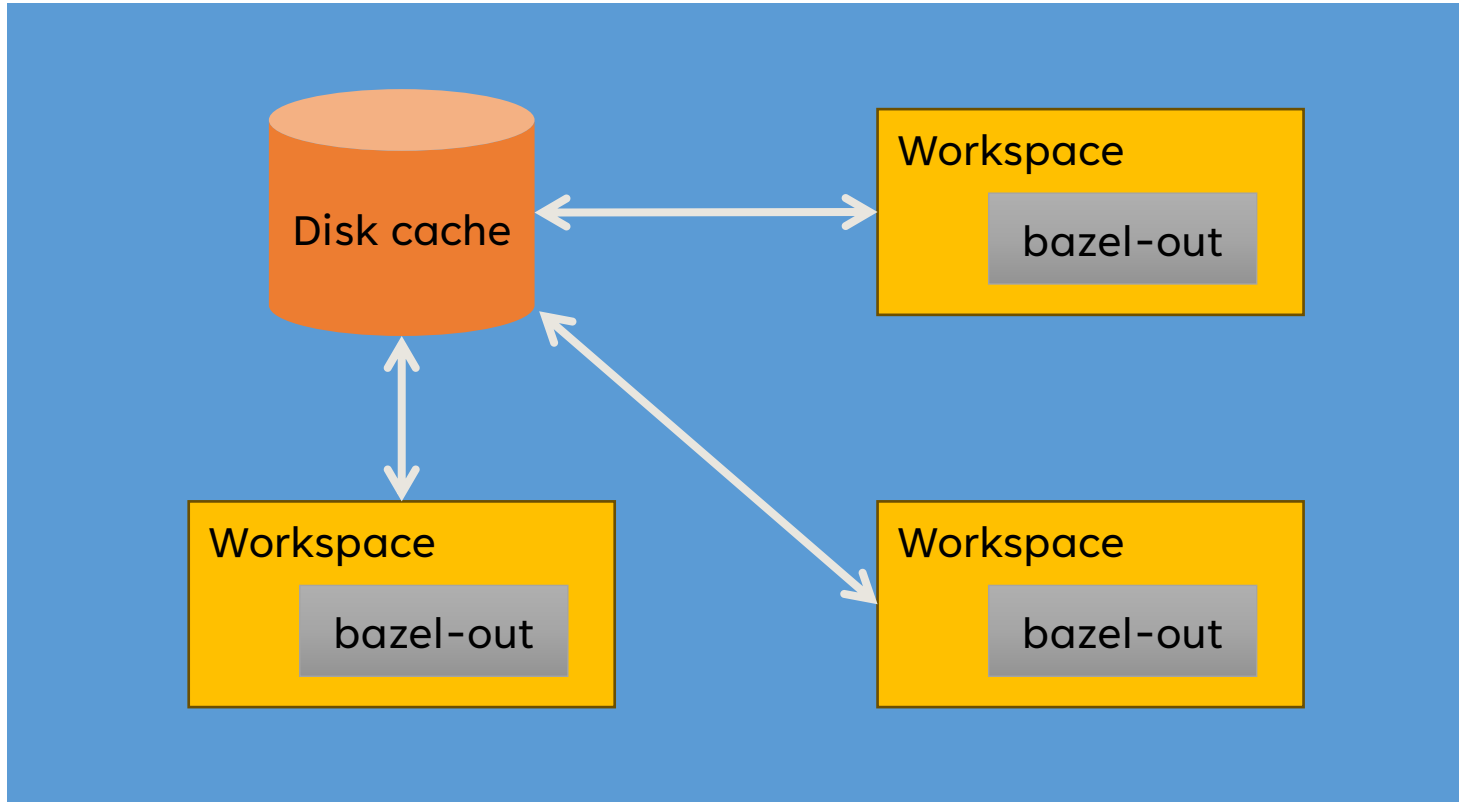
BAZEL CACHE

- Bazel cache “is always” valid and correct
  - The only reason why cache should be removed is to free space
  - Every time you solve a problem with bazel clean, a bug ticket should be created
    - It might be Bazel core:
      - https://github.com/bazelbuild/bazel/issues
    - It might be on some Bazel rules:
      - https://github.com/bazelbuild/rules_go/issues
      - https://github.com/bazelbuild/rules_python
      - https://github.com/bazelbuild/rules_docker
      - ...
    - It might be in one of your toolchain configurations
    - It might be in one of your Bazel extensions

https://bazel.build/remote/caching

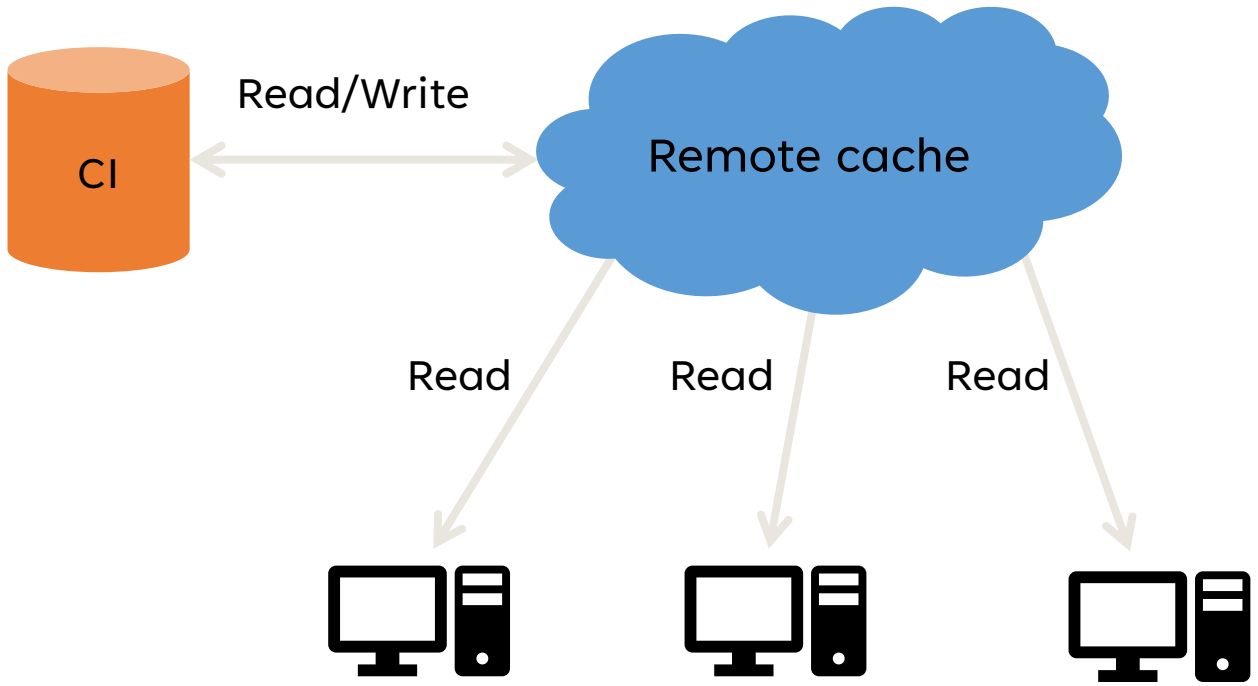
BAZEL LOCAL CACHE SETUP

- Common setup:



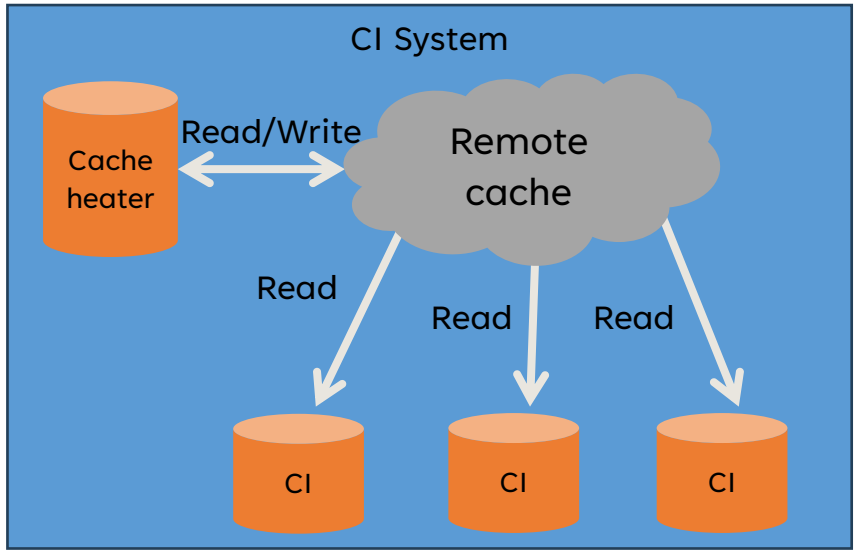
BAZEL REMOTE CACHE SETUP

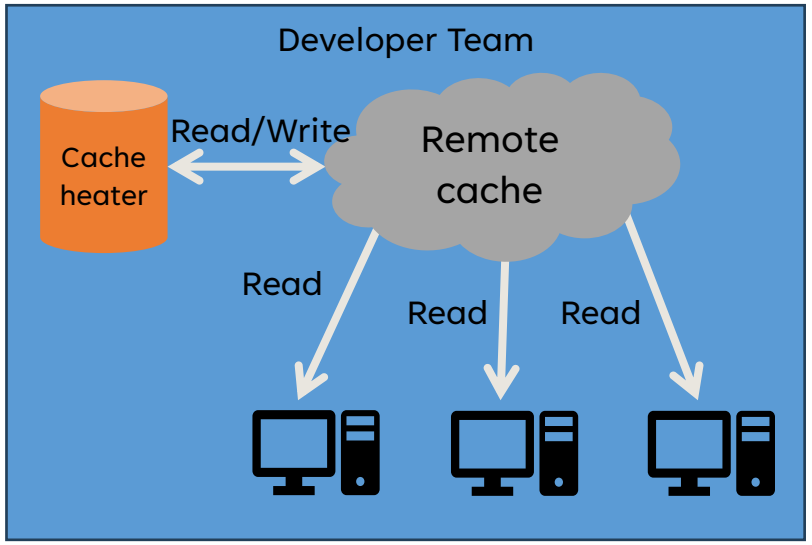
- Recommended setup:
  - CI read and write, developers read only

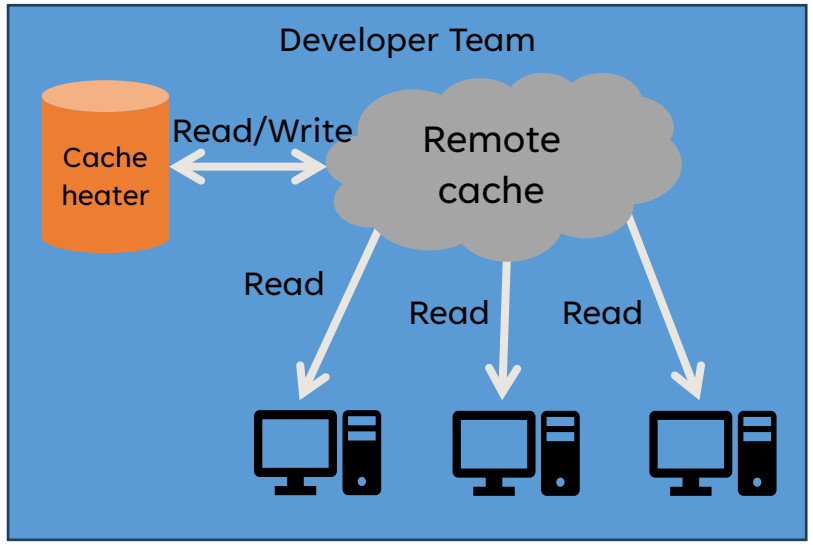


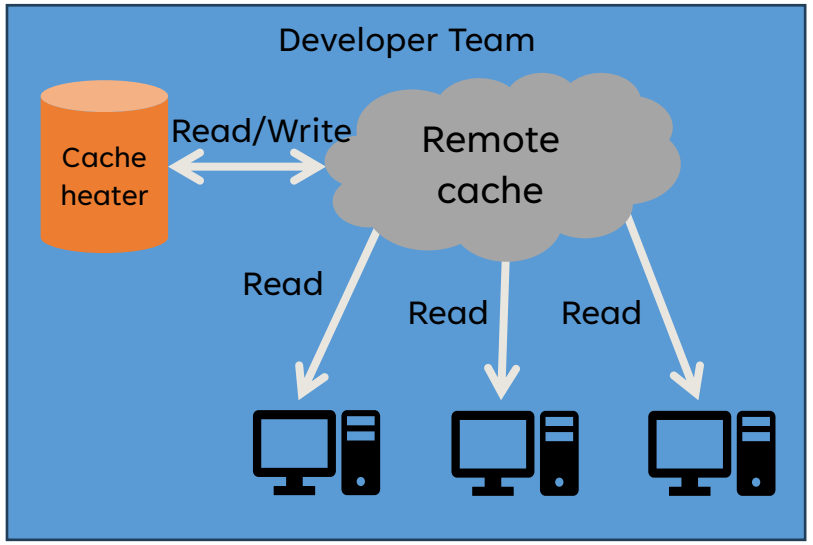
BAZEL REMOTE CACHE SETUP

- A more distributed approach:
  - One remote cache per developer team
  - One remote cache for CI only
  - On each remote cache one single entity writes to it
  - In addition, each developer uses disk cache



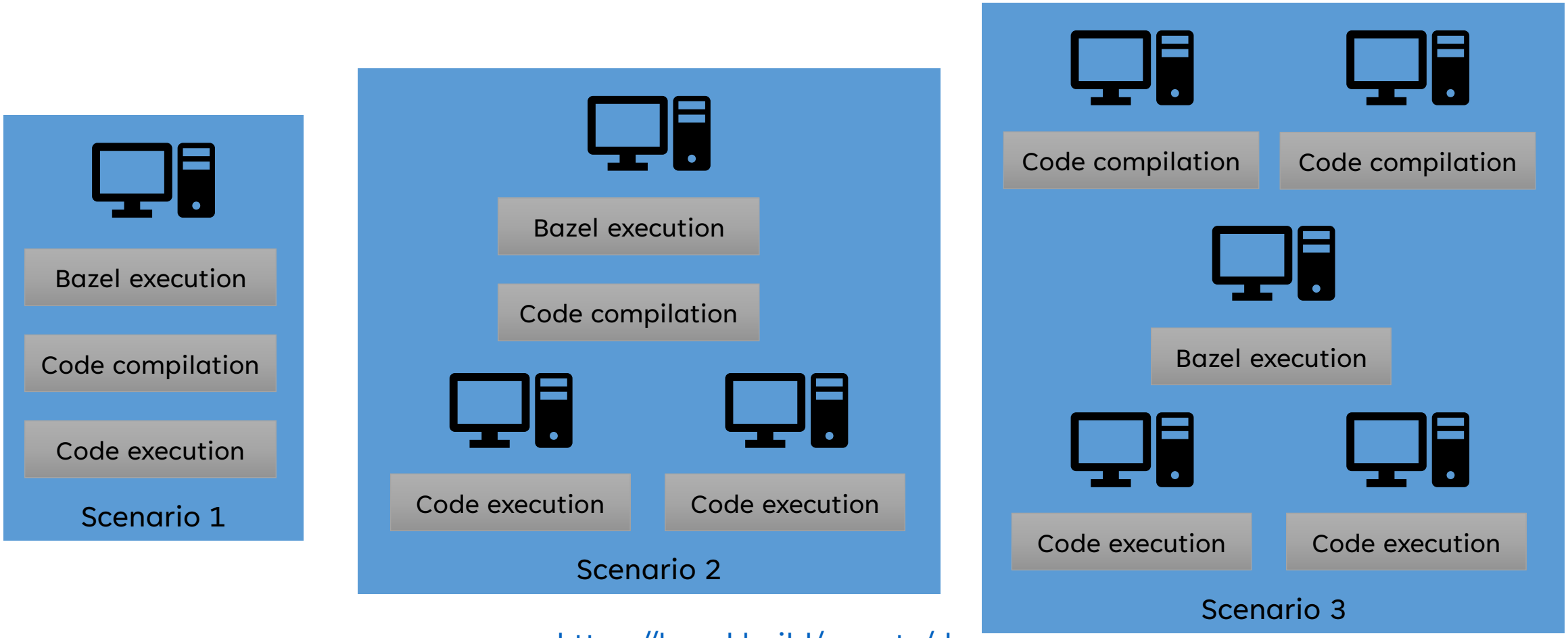






BAZEL REMOTE EXECUTION

- Bazel, compilation, and execution can run in different machines



https://bazel.build/remote/rbe

BAZEL FOR C++, PYTHON, AND RUST

- Basic rules for C++

```
load("@rules_cc//cc:defs.bzl", "cc_binary", "cc_library", "cc_shared_library",
"cc_static_library", "cc_test")
```

https://github.com/bazelbuild/rules_cc

- Basic rules for Python

```
load("@rules_python//python:defs.bzl", "py_binary", "py_library", "py_test")
```

https://github.com/bazel-contrib/rules_python

- Basic rules for Rust

```
load("@rules_rust//rust:defs.bzl", "rust_binary", "rust_library",
"rust_shared_library", "rust_static_library", "rust_test")
```

https://github.com/bazelbuild/rules_rust

BAZEL FOR C++, PYTHON, AND RUST

- Invoking Bazel:

```
> bazel run //:my_binary
> bazel build //:my_binary_library_or_test
> bazel test //:my_test
```

- Also with wildcards:

```
> bazel build //...
> bazel build //folder/subfolder/...
> bazel test //...
> bazel test //folder/subfolder/...
```

BUILD SYSTEM FOR PYTHON?

Compiled language

Compiled language

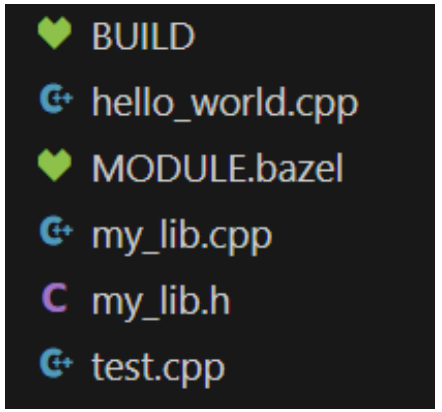
Interpreted language

- More difficult to leak dependencies with sandboxing
- Unified way to run your targets across languages
- You benefit from Bazel test utilities
- Apart from `bazel build`, you still need all the rest

C++ EXAMPLE WITH BAZEL

```
// MODULE.bazel
bazel_dep(name = "rules_cc", version = "0.2.0")

// BUILD
load("@rules_cc//cc:defs.bzl", "cc_binary", "cc_library")

cc_binary(
    name = "hello_world",
    srcs = ["hello_world.cpp"],
    deps = [":my_lib"],
)

cc_library(
    name = "my_lib",
    srcs = ["my_lib.cpp"],
    hdrs = ["my_lib.h"],
)
```

```
> bazel run //:hello_world
> bazel build //:hello_world
> bazel build //:my_lib
```



https://github.com/limdor/bazel-examples/tree/master/cpp

C++ EXAMPLE WITH BAZEL

```
// BUILD
load("@rules_cc//cc:defs.bzl", "cc_library", "cc_test")

cc_library(
    name = "my_lib",
    srcs = ["my_lib.cpp"],
    hdrs = ["my_lib.h"],
)

cc_test(
    name = "my_test",
    srcs = ["test.cpp"],
    deps = [":my_lib"],
)
```

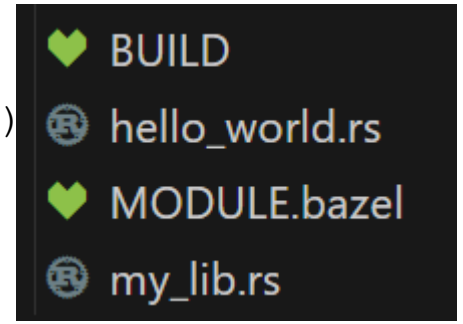
```
> bazel test //:my_test
//:my_test      PASSED in 0.0s
```

- BUILD
- hello_world.cpp
- MODULE.bazel
- my_lib.cpp
- my_lib.h
- test.cpp

https://github.com/limdor/bazel-examples/tree/master/cpp

C++ EXAMPLE WITH RUST

```
// MODULE.bazel
bazel_dep(name = "rules_rust", version = "0.63.0")

// BUILD
load("@rules_rust//rust:defs.bzl", "rust_binary", "rust_library")

rust_binary(
    name = "hello_world",
    srcs = ["hello_world.rs"],
    deps = [":my_lib"],
)

rust_library(
    name = "my_lib",
    srcs = ["my_lib.rs"],
)
```

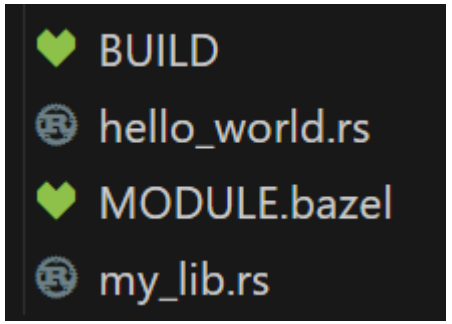



```
> bazel run //:hello_world
> bazel build //:hello_world
> bazel build //:my_lib
```

https://github.com/limdor/bazel-examples/tree/master/rust

C++ EXAMPLE WITH RUST

```
// BUILD
load("@rules_rust//rust:defs.bzl", "rust_library", "rust_test")

rust_library(
    name = "my_lib",
    srcs = ["my_lib.rs"],
)

rust_test(
    name = "my_test",
    crate = ":my_lib",
)
```

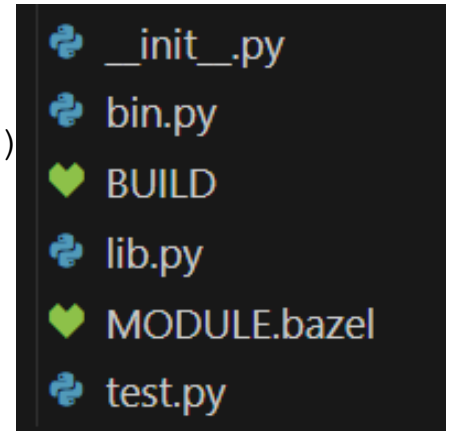



```
> bazel test //:my_test
//:my_test      PASSED in 0.0s
```

https://github.com/limdor/bazel-examples/tree/master/rust

PYTHON EXAMPLE WITH BAZEL

```
// MODULE.bazel
bazel_dep(name = "rules_python", version = "1.5.3")

// BUILD
load("@rules_python//python:defs.bzl", "py_binary", "py_library")

py_binary(
    name = "bin",
    srcs = ["bin.py"],
    deps = [":lib"],
)

py_library(
    name = "lib",
    srcs = [
        "__init__.py",
        "lib.py",
    ],
)
```

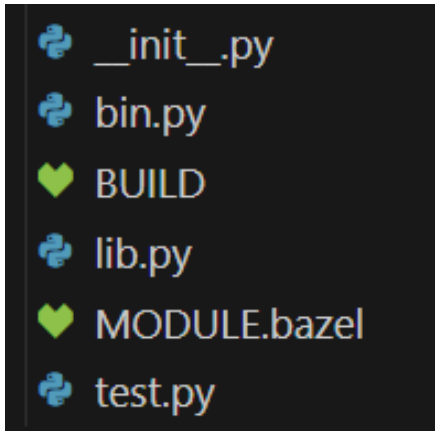



```
> bazel run //:bin
> bazel build //:lib
Target //:lib up-to-date (nothing to build)
> bazel run //:lib
ERROR: Cannot run target //:lib: Not executable
```

https://github.com/limdor/bazel-examples/tree/master/python

PYTHON EXAMPLE WITH BAZEL

```
// BUILD
load("@rules_python//python:defs.bzl", "py_library", "py_test")

py_library(
    name = "lib",
    srcs = [
        "__init__.py",
        "lib.py",
    ],
)

py_test(
    name = "test",
    srcs = ["test.py"],
    deps = [":lib"],
)
```



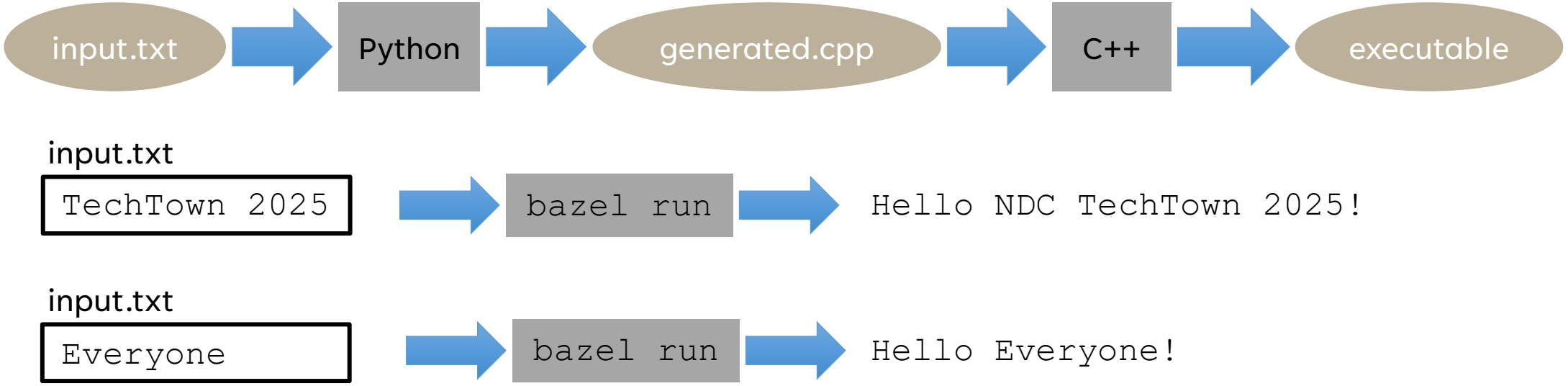

```
> bazel test //:test
//:test        PASSED in 0.1s
```

https://github.com/limdor/bazel-examples/tree/master/python

COMPILE C++ CODE GENERATED WITH PYTHON

- Bazel can be extended using macros and/or rules
  - https://bazel.build/extending/macros
  - https://bazel.build/extending/rules

- Example:



https://github.com/limdor/bazel-examples/tree/master/cpp_and_python

COMPILE C++ CODE GENERATED WITH PYTHON

- The generator:
  - generator.py and BUILD file

```python
import argparse

def main():
    parser = argparse.ArgumentParser()
    parser.add_argument("input_file", help="Text file with message")
    parser.add_argument("output_file", help="Cpp file hello world program")
    args = parser.parse_args()
    hello_world_message = "World"
    with open(args.input_file, 'r') as message_file:
        hello_world_message = message_file.readline()
    with open(args.output_file, 'w') as hello_world_program_file:
        hello_world_program_file.write('#include <iostream>\n')
        hello_world_program_file.write('\n')
        hello_world_program_file.write('int main()\n')
        hello_world_program_file.write('{\n')
        hello_world_program_file.write(f'    std::cout << "Hello {hello_world_message}!" << std::endl;\n')
        hello_world_program_file.write('}\n')

if __name__ == "__main__":
    main()
```

```bazel
load("@rules_python//python:defs.bzl", "py_binary")

py_binary(
    name = "generator",
    srcs = ["generator.py"],
    visibility = ["//visibility:public"],
)
```

https://github.com/limdor/bazel-examples/tree/master/cpp_and_python

COMPILE C++ CODE GENERATED WITH PYTHON

- The macro definition:
  - generator.bzl

```
"""
Macro to generate a hello world cpp file
"""

def _hello_world_impl(name, visibility, **kwargs):
    native.genrule(
        name = name,
        srcs = [":" + name + ".txt"],
        outs = [name + ".cpp"],
        cmd = "$(location //hello_world:generator) $< $@",
        tools = ["//hello_world:generator"],
        visibility = visibility,
        **kwargs
    )

hello_world = macro(
    implementation = _hello_world_impl,
)
```

- The macro invocation:
  - BUILD

```
load("@rules_cc//cc:defs.bzl", "cc_binary")
load("//hello_world:generator.bzl", "hello_world")

exports_files(
    srcs = ["ndc_techtown.txt"],
)

hello_world(
    name = "ndc_techtown",
)

cc_binary(
    name = "hello_world_ndc_techtown",
    srcs = [":ndc_techtown"],
)
```

https://github.com/limdor/bazel-examples/tree/master/cpp_and_python

BAZEL TOOLCHAINS

- Wait! If it is so hermetic, why we did not have to specify our compiler?
  - For practical reasons Bazel provide some predefined toolchains that can be used if some compilers are installed in your machine
  - The option `--toolchain_resolution_debug` can be used to see what toolchains are being used
    `Selected @@rules_cc++cc_configure_extension+local_config_cc//:cc-compiler-k8`
  - Still for any production project, you should be defining a hermetic toolchain
    - Defining a toolchain is not enough if it points to a locally installed compiler
    - Compilers and linkers should be provided like any input artifact
    - Python interpreter should be provided like any input artifact
    - If a user needs to install something in his machine apart from Bazel , you are doing something wrong
  - Bazel provide a lot of documentation on how to define toolchains
    - https://bazel.build/tutorials/ccp-toolchain-config
    - https://bazel.build/extending/toolchains

https://bazel.build/extending/toolchains

BAZEL TEST RUNNER

- All testing infrastructure provided by Bazel is language agnostic
- When using wildcards it runs all rules `*_test` (`cc_test`, `py_test`, `rust_test`, etc.)
  `bazel test //...`
- Except the ones that have `manual` in the `tags` parameter (deactivated)
- The ones with `flaky` flag set to `True` , will be rerun automatically if they fail
- Tests will timeout depending on the value in `timeout` and `size` parameters
- Tests run in parallel unless `exclusive` is specified in the `tags`
- The output of the test is stored to a file and displayed to the console in case that it fails
- The output can be showed interactively specifying `--test_output =streamed`, but then the tests do not run in parallel
- If a library sets the `testonly` parameter, that library can only be used by testonly targets
- If a test or its dependencies did not change, the test will not be executed
  `//:my_test (cached) PASSED in 0.0s`

```
cc_test(
  name = "disabled_test",
  tags = ["manual"],
  ...
)

rust_test(
  name = "flaky_test",
  flaky = True,
  ...
)

py_test(
  name = "small_test",
  timeout = "short",
  size = "small",
  ...
)

cc_library(
  name = "test_lib",
  srcs = ["my_lib.cpp"],
  testonly = True,
  hdrs = ["my_lib.h"],
)
```

https://bazel.build/reference/test-encyclopedia

BAZEL TEST RUNNER

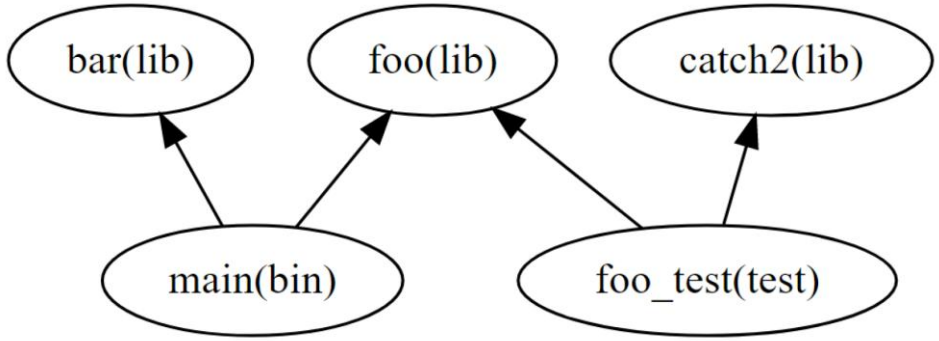
- In the end Bazel prints a summary of all executed tests

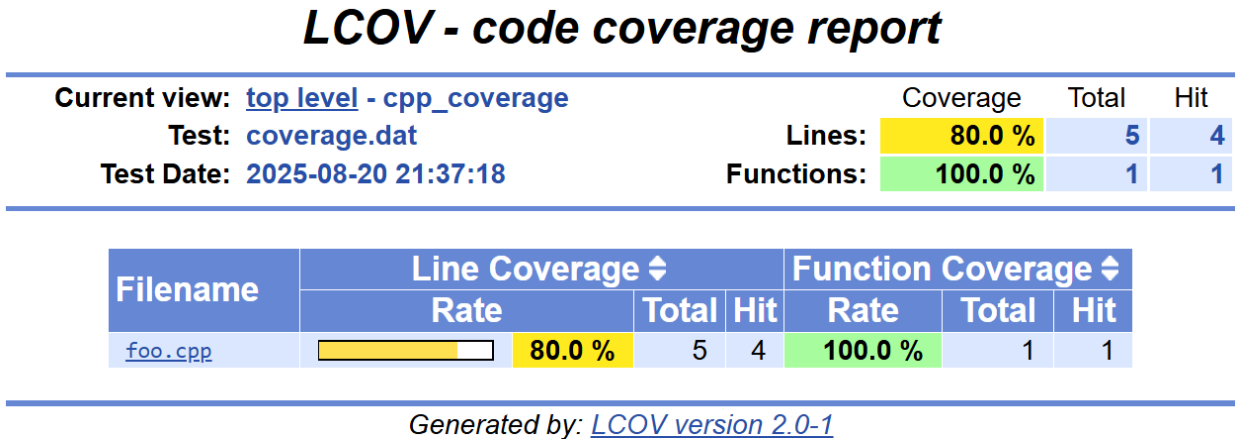
```
//:my_cpp_test          (cached) PASSED in 0.0s
//:my_python_test                PASSED in 0.0s
//:my_flaky_test                 FLAKY, failed in 2 out of 3 in 2.0s
  Stats over 3 runs: max = 2.0s, min = 2.0s, avg = 2.0s, dev = 0.0s

/path/to/the/teslogs/folder/my_flaky_test/test_attempts/attempt_1.log

/path/to/the/teslogs/folder/my_flaky_test/test_attempts/attempt_2.log
//:my_fail_test                  FAILED in 2.0s
  /path/to/the/teslogs/folder/my_fail_test/test.log
//:my_build_errors_test          FAILED TO BUILD
//:my_too_long_test              TIMEOUT in 60.0s
  /path/to/the/teslogs/folder/my_too_long_test/test.log
```

https://bazel.build/reference/test-encyclopedia

BAZEL COVERAGE

- Bazel provides a command line to compute code coverage
  `bazel coverage //:foo_test`
- Runs the tests and collects coverage information
- Afterwards, a report can be generated
  `genhtml –output-directory coverage-report bazel-testlogs/foo_test/coverage.dat`





LCOV - code coverage report

			Coverage	Total	Hit
Current view:	top level - cpp_coverage				
Test:	coverage.dat	**Lines:**	80.0 %	5	4
Test Date:	2025-08-20 21:37:18	**Functions:**	100.0 %	1	1

Filename	Line Coverage			Function Coverage		
	Rate		Total	Hit	Rate	Total	Hit
foo.cpp		80.0 %	5	4	100.0 %	1	1

Generated by: LCOV version 2.0-1

- Baseline coverage is not supported out of the box
  - https://github.com/bazelbuild/bazel/issues/5716

https://github.com/limdor/bazel-examples/tree/master/cpp_coverage

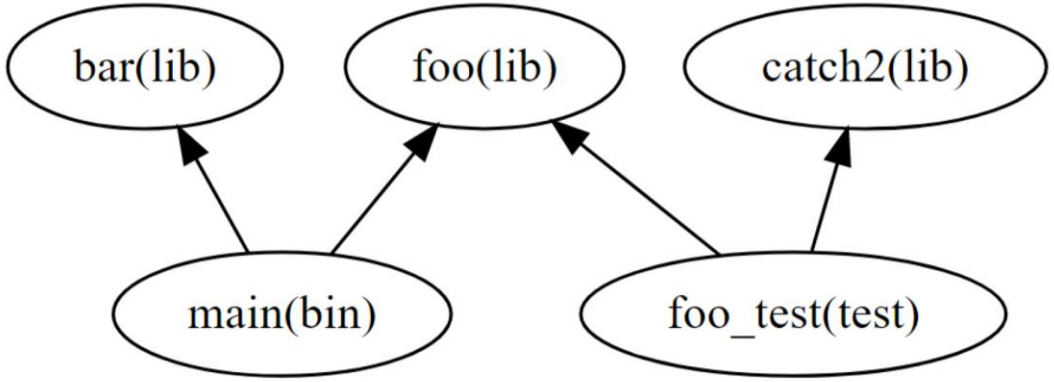
BAZEL QUERY

- Bazel provides three commands to understand the build graph

```
bazel query //:foo_test
bazel cquery //:foo_test
bazel aquery //:foo_test
```

- `> bazel query "deps(//:foo_test)" --notool_deps --noimplicit_deps`

```
//:foo_test
@catch2//:catch2
@catch2//:single_include/catch2/catch.hpp
//:foo_test.cpp
//:foo
//:foo.h
//:foo.cpp
```



https://bazel.build/query/guide

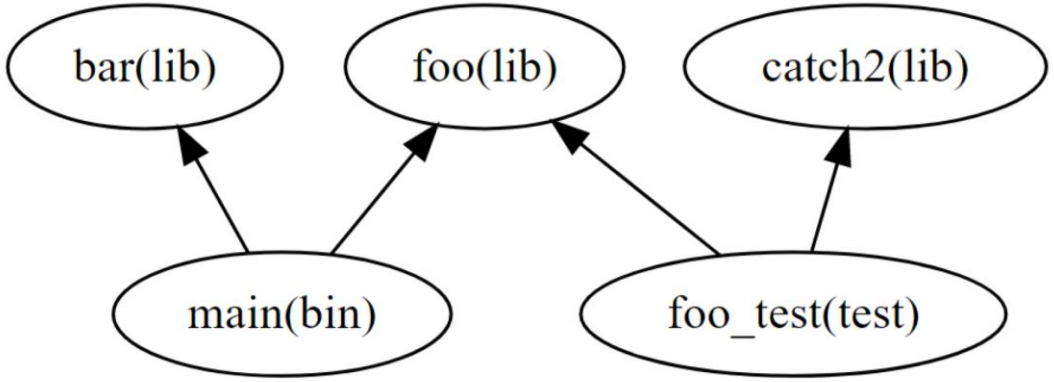
BAZEL QUERY

- How foo_test depends on foo.h?

```
> bazel query "somepath(//:foo_test, //:foo.h)" --notool_deps --noimplicit_deps
//:foo_test
//:foo
//:foo.h
```

- How foo_test depends on bar library?

```
> bazel query "somepath(//:foo_test, //:bar)“ --notool_deps --noimplicit_deps
INFO: Empty results
```



https://bazel.build/query/guide

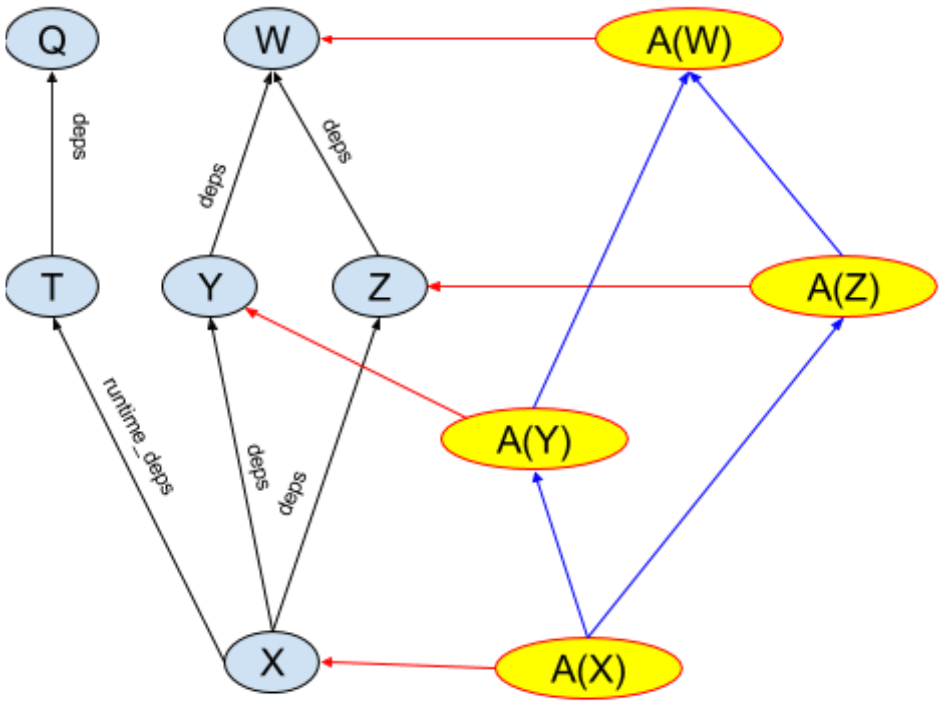
BAZELISK

- It is a launcher for Bazel
- It allows to use multiple Bazel versions in one machine/workspace
- Developers do not need to care about upgrading Bazel
- Some ways that can be used:
  - Define an environment variable called USE_BAZEL_VERSION specifying the version to be used
  - Check in a file with the name `.bazelversion` to your repository containing the version to be used
  - If no version is specified, it will always use the latest Bazel version released
- It can be run like Bazel
  `> bazelisk run //: hello_world`
- Or you can put it to your binary path named as `bazel`
- When running it with `--strict` and `--migrate` can help in the migration process to a newer Bazel version

https://github.com/bazelbuild/bazelisk

BAZEL ASPECTS

- Bazel provide also aspects
  - Allows to add additional information to the dependency graph
  - For what could be used?
    - IDE integration
    - Static analysis
    - Code coverage
    - Compiler warnings
    - . . .



https://bazel.build/extending/aspects

BAZEL COMMANDS

- `bazel help` Show all commands, can be used with a specific command (`bazel help build`)
- `bazel version` Show Bazel version, can be different per workspace if using bazelisk
- `bazel build` Build targets, provides the option to run only loading and analysis phase
- `bazel run` Should be used to run the targets, takes care of runtime dependencies
- `bazel test` Basic command to execute your tests with a lot of helpful options
- `bazel coverage` Should be used to compute code coverage, not fully supported for all languages
- `bazel query` Retrieve information from the build graph without running the analysis phase
- `bazel cquery` Retrieve information from the build graph after running the analysis phase
- `bazel aquery` Allow you to query information regarding the actions in the build graph
- `bazel print_action` Print action information for a given target
- `bazel mod` Display information about Bzlmod external dependency graph
- `bazel clean` If you must run it, there is a bug somewhere

https://bazel.build/reference/command-line-reference#commands

INTRODUCTION TO BAZEL

Xavier Bonaventura