just, a generic open-source build system

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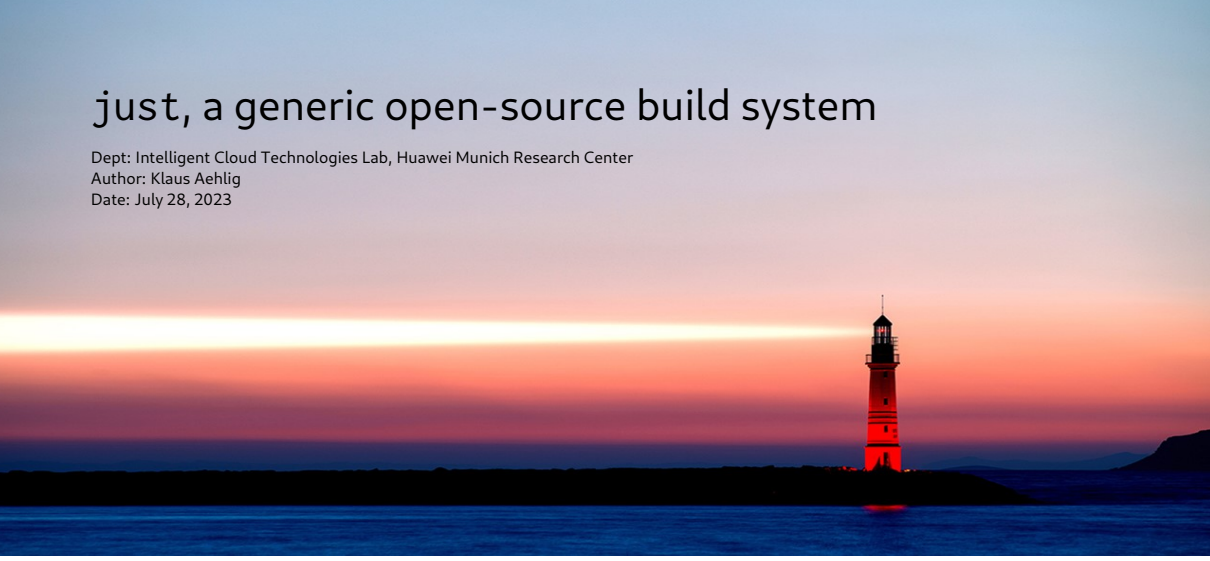
Author: Klaus Aehlig
Date: July 28, 2023



HUAWEI

Introduction

- `justbuild` is an open-source software build system (Apache 2.0 license)
  - Version 1.0.0 on December 12, 2022
  - active ongoing development
- Designed and built from scratch
  - no legacy requirements
  - can explore new ideas (staging, target-level caching, …)

  … but building on successful ideas of existing tools
- Recall: a build system
  - computes a function (from source tree to artifacts)
  - uses concepts meaningful to a programmer (“library”, “binary”, …)
    not: individual compiler invocations, object files, …
  - must be correct, should be fast

just Example

```
$ cat TARGETS
{ "helloworld":
  { "type": ["@", "rules", "CC", "binary"]
  , "name": ["helloworld"]
  , "srcs": ["main.cpp"]
  , "private-deps": ["libhello"]
  }
, "libhello":
  { "type": ["@", "rules", "CC", "library"]
  , "name": ["hello"]
  , "srcs": ["hello.cpp"]
  , "hdrs": ["hello.hpp"]
  , "deps": ["utils"]
  }
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  , "name": ["utils"]
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  }
}
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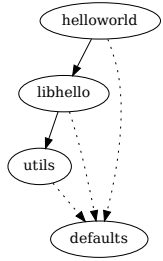

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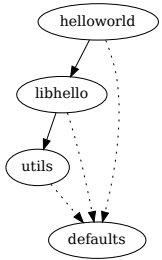

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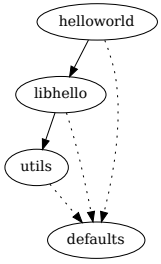

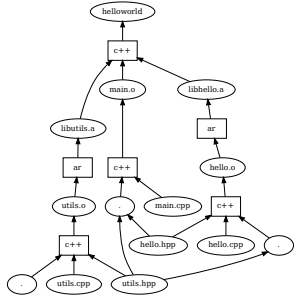

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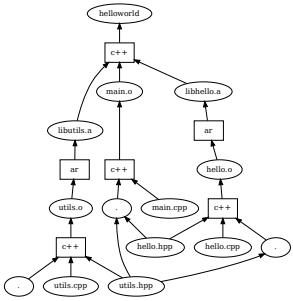

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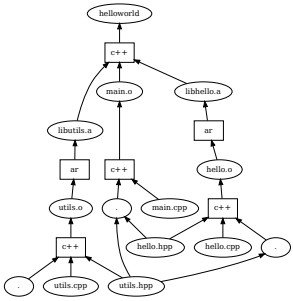


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$ just build -C repos.json helloworld
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INFO: Analysed target [["@","","","helloworld"],{}]
INFO: Discovered 6 actions, 3 trees, 0 blobs
INFO: Building [["@","","","helloworld"],{}].
INFO: Processed 6 actions, 0 cache hits.
INFO: Artifacts built, logical paths are:
        helloworld [9dafb06bf5eacc62eb8f538ab1e4dab8a6339dc3:24704:x]
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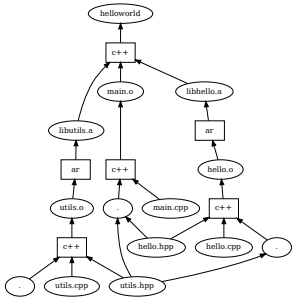


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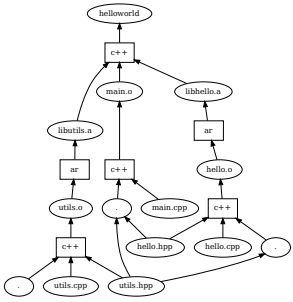
INFO: Discovered 6 actions, 3 trees, 0 blobs
INFO: Building [["@","","","helloworld"],{}].
INFO: Processed 6 actions, 6 cache hits.
INFO: Artifacts can be found in:
      /worker/build/62dbe7fb60915e38/root/work/helloworld/./helloworld [9dafb06bf5eacc62eb8f538ab1e4dab8a6339dc3:2
$
```

just Example

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$ ./helloworld
Hello World!
$
```

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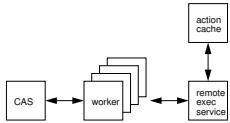
  - using an action cache (AC)



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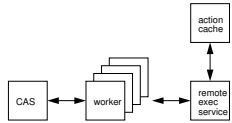

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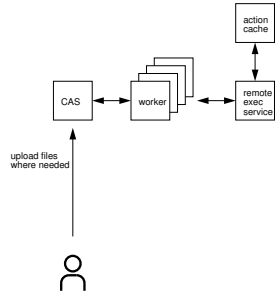

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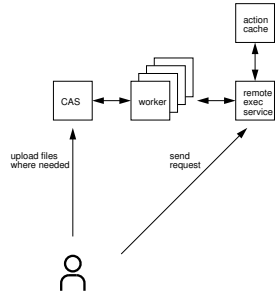

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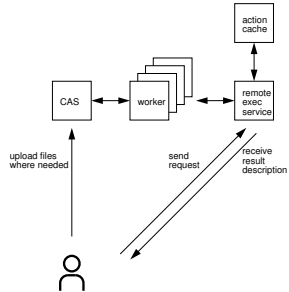

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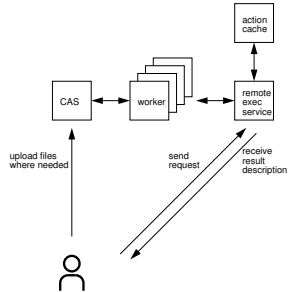

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- actual artifacts can be downloaded from CAS, should they be needed

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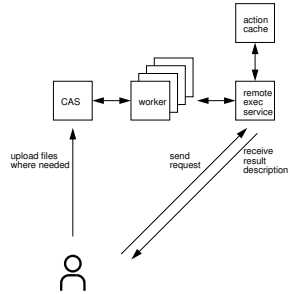

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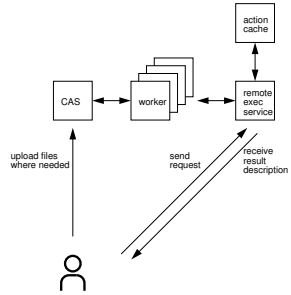

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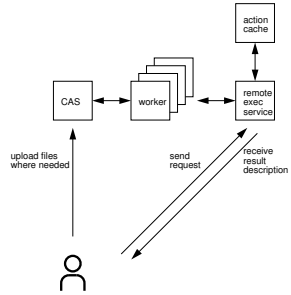

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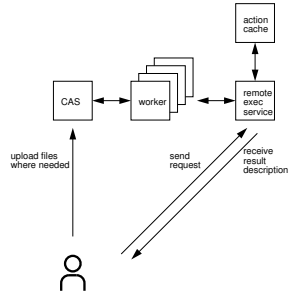

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As people use `git` as VCS, let's use `git` blob/tree identifiers everywhere!

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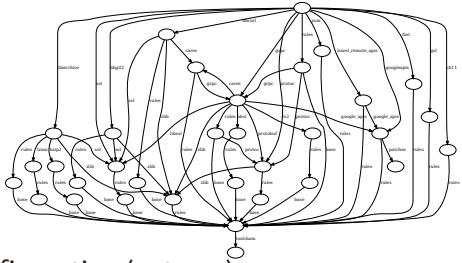

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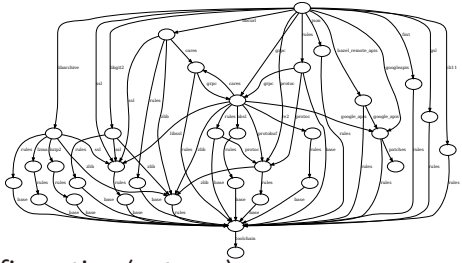

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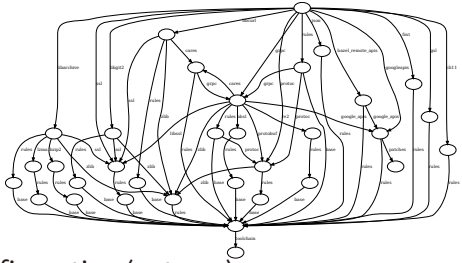

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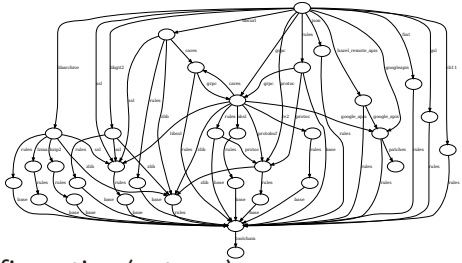

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  (and use one default repository to store everything)
- Additional benefit: target-level caching if reachable part of DFA unchanged
  (minimal DFA as canonical representation; plus target name, configuration)
  ⇝ keep graphs to handle small; still flexible to build in different configurations

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    { "repository": {"type": "file", "path": "src"}
    , "bindings": {"rules": "rules-cc"}
    }
  , "test":
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```

```
#!/bin/sh
set -eu
readonly ROOT=$(readlink -f $(dirname $0)/..)

just-import-git -C ${ROOT}/etc/repos.template.json \
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- Simply use by: `just-mr build`
  (or `just-mr --main test build`)
  - `just-mr` fetches the dependencies (if commit not present already)
  - then launches `just` with the correct repository configuration

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  - the actual artifact, like `libfoo.a`
  - additional files that should be installed with the target, like headers
  - any additional information needed to use the target
    (no reflection on the dependency graph!)
    - Headers of public dependencies
    - Information on how to link, including libraries depended upon
    - …

Rules: Data of a Target (Example)

```
$ cat TARGETS
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  }
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$
```

Rules: Data of a Target (Example)

```
$ just analyse -C repos.json libhello
INFO: Requested target is [["@","","","libhello"],{}]
INFO: Result of target [["@","","","libhello"],{}]: {
        "artifacts": {
          "libhello.a": {"data":{"id":"bfd40392f507f1cea464b32003b0b7f79f70cf2f","path":"libhello.a"},"type":"ACTION"}
        },
        "provides": {
          "compile-args": [
          ],
          "compile-deps": {
            "utils.hpp": {"data":{"path":"utils.hpp","repository":""},"type":"LOCAL"}
          },
          "link-args": [
            "libhello.a",
            "libutils.a"
          ],
          "link-deps": {
            "libutils.a": {"data":{"id":"b8b7e151fc1a3c73f7cd3b8d6f6bcc2a353493a1","path":"libutils.a"},"type":"ACTION"}
          },
          "package": {
            "cflags-files": {},
            "ldflags-files": {},
            "name": "hello"
          }
        },
        "runfiles": {
          "hello.hpp": {"data":{"path":"hello.hpp","repository":""},"type":"LOCAL"}
        }
      }
$
```

Rule Language

Rules are mainly given by a functional expression defining this value; language

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- variables, `let*`-binding, conditional expressions, ...
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- actions are a means to define artifacts
  - function returning a map of the output artifacts
  - inputs: stage of input artifacts, command vector, environment, expected outputs *(as well as execution properties, timeout-related information, …)*
  - mathematical function $\rightsquigarrow$ intensional equality on artifacts

Equality: Intensional versus Extensional

```
$ cat TARGETS
{ "foo":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo Hello World > out.txt"]
  }
, "bar":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo Hello World > out.txt"]
  }
, "baz":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo -n Hello > out.txt && echo ' World' >> out.txt"]
  }
, "foo upper":
  { "type": "generic"
  , "deps": ["foo"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "bar upper":
  { "type": "generic"
  , "deps": ["bar"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "baz upper":
  { "type": "generic"
  , "deps": ["baz"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "ALL":
  { "type": "install"
  , "files":
    {"foo.txt": "foo upper", "bar.txt": "bar upper", "baz.txt": "baz upper"}
  }
}
$
```

Equality: Intensional versus Extensional

```
$ cat TARGETS && just build -J 1
{ "foo":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo Hello World > out.txt"]
  }
, "bar":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo Hello World > out.txt"]
  }
, "baz":
  { "type": "generic"
  , "outs": ["out.txt"]
  , "cmds": ["echo -n Hello > out.txt && echo ' World' >> out.txt"]
  }
, "foo upper":
  { "type": "generic"
  , "deps": ["foo"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "bar upper":
  { "type": "generic"
  , "deps": ["bar"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "baz upper":
  { "type": "generic"
  , "deps": ["baz"]
  , "outs": ["upper.txt"]
  , "cmds": ["cat out.txt | tr a-z A-Z > upper.txt"]
  }
, "ALL":
  { "type": "install"
  , "files":
    {"foo.txt": "foo upper", "bar.txt": "bar upper", "baz.txt": "baz upper"}
  }
}
INFO: Requested target is [["@","","","ALL"],{}]
INFO: Analysed target [["@","","","ALL"],{}]
INFO: Discovered 4 actions, 0 trees, 0 blobs
INFO: Building [["@","","","ALL"],{}].
INFO: Processed 4 actions, 1 cache hits.
INFO: Artifacts built, logical paths are:
       bar.txt [4e3dffe834ac70600a7cb71fbc1f6a694c9d041f:12:f]
       baz.txt [4e3dffe834ac70600a7cb71fbc1f6a694c9d041f:12:f]
       foo.txt [4e3dffe834ac70600a7cb71fbc1f6a694c9d041f:12:f]
$
```

Reproducible Builds

- We consider build actions as functions—should also behave as such!

⇝ Reproducible builds (see also `https://reproducible-builds.org/`)

- Why
  - Independent verification possible that the binaries were built from those sources
  - Reconstruct the precise binary you used at a particular point in time
  - Also: more cache hits (if actions fall out of cache; formatting, comments, …)
- How
  - Don't include time stamps (other than `SOURCE_DATE_EPOCH`), working directory, hostname, user name, …
  - Don't rely on `readdir` order, non-specified behaviour, race conditions, …
  - Fix your enviroment: dependencies, tool chains, …—or bootstrap them!
- Also verify: `just rebuild`

Rebuilding

```
$ cat TARGETS
{ "":
  { "type": ["@", "rules", "CC", "binary"]
  , "name": ["hello"]
  , "srcs": ["main.cpp", "version.cpp", "greet.cpp"]
  , "private-hdrs": ["version.hpp", "greet.hpp"]
  }
}
$
```

Rebuilding

```
$ cat TARGETS
{ "":
  { "type": ["@", "rules", "CC", "binary"]
  , "name": ["hello"]
  , "srcs": ["main.cpp", "version.cpp", "greet.cpp"]
  , "private-hdrs": ["version.hpp", "greet.hpp"]
  }
}
$

$ just-mr build
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","build","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02"]
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Building [["@","","",""],{}].
INFO: Processed 4 actions, 0 cache hits.
INFO: Artifacts built, logical paths are:
       hello [2f47037aef458e6a8cc131b865ec795041922e0e:17616:x]
$
```

Rebuilding

```
$ just-mr build
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","build","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02"]
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INFO: Analysed target [["@","","",""],{}]
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INFO: Building [["@","","",""],{}].
INFO: Processed 4 actions, 0 cache hits.
INFO: Artifacts built, logical paths are:
       hello [2f47037aef458e6a8cc131b865ec795041922e0e:17616:x]
$

$ just-mr rebuild
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","rebuild","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02"]
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Rebuilding [["@","","",""],{}].
INFO: 4 actions compared with cache.
INFO: Artifacts built, logical paths are:
       hello [2f47037aef458e6a8cc131b865ec795041922e0e:17616:x]
$
```

Rebuilding

```
$ just-mr build
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","build","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02"]
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Building [["@","","",""],{}].
INFO: Processed 4 actions, 0 cache hits.
INFO: Artifacts built, logical paths are:
       hello [2f47037aef458e6a8cc131b865ec795041922e0e:17616:x]
$

$ just-mr rebuild -L '["env", "--", "FAKETIME=1970-01-01 00:00:00", "LD_PRELOAD='$PREFIX'/lib/libfaketime.so.1"]'
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","rebuild","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02","-L"
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Rebuilding [["@","","",""],{}].
WARN: Found flaky action:
      - id: afad430115d04a713e0de06770ca63e43f2f8dfe
      - cmd: ["c++","-I","work","-isystem","include","-c","work/version.cpp","-o","work/version.o"]
      - output 'work/version.o' differs:
        - [b951c2204c8e9a083d869817493acb28dc10cb0d:2792:f] (rebuilt)
        - [55f0079885057b199446bceb6b82fe0fe7f21def:2792:f] (cached)
INFO: 3 actions compared with cache, 1 flaky actions found (0 of which tainted), no cache entry found for 1 actions.
INFO: Artifacts built, logical paths are:
       hello [4095831467e82db7f2980b620deecf8f44dcc813:17616:x]
$
```

Rebuilding

```
$ just-mr build
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","build","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02"]
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Building [["@","","",""],{}].
INFO: Processed 4 actions, 0 cache hits.
INFO: Artifacts built, logical paths are:
       hello [2f47037aef458e6a8cc131b865ec795041922e0e:17616:x]
$

$ just-mr rebuild -L '["env", "--", "FAKETIME=1970-01-01 00:00:00", "LD_PRELOAD='$PREFIX'/lib/libfaketime.so.1"]' --dump-flaky flaky.json
INFO: Performing repositories setup
INFO: Found 2 repositories to set up
INFO: Setup finished, exec ["just","rebuild","-C","/worker/build/62bec0ed32723571/root/home/.cache/just/protocol-dependent/generation-0/git-sha1/casf/cd/e7ff54cc85bad8b8f5b1fedc42d1c03e884b02","-L"
INFO: Requested target is [["@","","",""],{}]
INFO: Analysed target [["@","","",""],{}]
INFO: Discovered 4 actions, 1 trees, 0 blobs
INFO: Rebuilding [["@","","",""],{}].
WARN: Found flaky action:
      - id: afad430115d04a713e0de06770ca63e43f2f8dfe
      - cmd: ["c++","-I","work","-isystem","include","-c","work/version.cpp","-o","work/version.o"]
      - output 'work/version.o' differs:
        - [b951c2204c8e9a083d869817493acb28dc10cb0d:2792:f] (rebuilt)
        - [55f0079885057b199446bceb6b82fe0fe7f21def:2792:f] (cached)
INFO: 3 actions compared with cache, 1 flaky actions found (0 of which tainted), no cache entry found for 1 actions.
INFO: Artifacts built, logical paths are:
       hello [4095831467e82db7f2980b620deecf8f44dcc813:17616:x]
$
```

Rebuilding (cont'd)

```
$ cat flaky.json
{
  "cache misses": [
    "f94e0c38ca48c0ae590b81db7075537f8e480d69"
  ],
  "flaky actions": {
    "afad430115d04a713e0de06770ca63e43f2f8dfe": {
      "work/version.o": {
        "cached": {
          "file_type": "f",
          "id": "55f0079885057b199446bceb6b82fe0fe7f21def",
          "size": 2792
        },
        "rebuilt": {
          "file_type": "f",
          "id": "b951c2204c8e9a083d869817493acb28dc10cb0d",
          "size": 2792
        }
      }
    }
  }
}$
```

Rebuilding (cont'd)

```
$ cat flaky.json
{
  "cache misses": [
    "f94e0c38ca48c0ae590b81db7075537f8e480d69"
  ],
  "flaky actions": {
    "afad430115d04a713e0de06770ca63e43f2f8dfe": {
      "work/version.o": {
        "cached": {
          "file_type": "f",
          "id": "55f0079885057b199446bceb6b82fe0fe7f21def",
          "size": 2792
        },
        "rebuilt": {
          "file_type": "f",
          "id": "b951c2204c8e9a083d869817493acb28dc10cb0d",
          "size": 2792
        }
      }
    }
  }
}$
```

```
$ for b in `jq -rM '."flaky actions" | .[] | .[] | .[] | .id ' flaky.json`
      do just install-cas $b | od -t x1 > blob-$b
  done
  diff -u blob*
--- blob-55f0079885057b199446bceb6b82fe0fe7f21def   2023-07-14 11:10:46.393008231 +0000
+++ blob-b951c2204c8e9a083d869817493acb28dc10cb0d   2023-07-14 11:10:46.425008450 +0000
@@ -17,8 +17,8 @@
 0000400 89 c7 e8 00 00 00 00 48 89 d8 48 89 c7 e8 00 00
 0000420 00 00 48 8b 85 68 fe ff ff 48 8b 5d f8 c9 c3 48
 0000440 65 6c 6c 6f 20 57 6f 72 6c 64 20 31 2e 30 00 2c
-0000460 20 28 63 29 20 00 4a 75 6c 20 31 34 20 32 30 32
-0000500 33 00 20 45 78 61 6d 70 6c 65 2e 63 6f 6d 00 ff
+0000460 20 28 63 29 20 00 4a 61 6e 20 20 31 20 31 39 37
+0000500 30 00 20 45 78 61 6d 70 6c 65 2e 63 6f 6d 00 ff
 0000520 ff 01 0e 1d 05 00 00 36 61 a9 01 00 c1 01 05 00
 0000540 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 0000560 00 47 43 43 3a 20 28 44 65 62 69 61 6e 20 31 32
$
```

Rebuilding (cont'd)

```
$ cat flaky.json
{
  "cache misses": [
    "f94e0c38ca48c0ae590b81db7075537f8e480d69"
  ],
  "flaky actions": {
    "afad430115d04a713e0de06770ca63e43f2f8dfe": {
      "work/version.o": {
        "cached": {
          "file_type": "f",
          "id": "55f0079885057b199446bceb6b82fe0fe7f21def",
          "size": 2792
        },
        "rebuilt": {
          "file_type": "f",
          "id": "b951c2204c8e9a083d869817493acb28dc10cb0d",
          "size": 2792
        }
      }
    }
  }
}$
```

```
$ for b in `jq -rM '."flaky actions" | .[] | .[] | .[] | .id ' flaky.json`
      do just install-cas $b | od -t x1 > blob-$b
  done
  diff -u blob*
--- blob-55f0079885057b199446bceb6b82fe0fe7f21def   2023-07-14 11:10:46.393008231 +0000
+++ blob-b951c2204c8e9a083d869817493acb28dc10cb0d   2023-07-14 11:10:46.425008450 +0000
@@ -17,8 +17,8 @@
 0000400 89 c7 e8 00 00 00 48 89 d8 48 89 c7 e8 00 00
 0000420 00 00 48 8b 85 68 fe ff ff 48 8b 5d f8 c9 c3 48
 0000440 65 6c 6c 6f 20 57 6f 72 6c 64 20 31 2e 30 00 2c
-0000460 20 28 63 29 20 00 4a 75 6c 20 31 34 20 32 30 32
-0000500 33 00 20 45 78 61 6d 70 6c 65 2e 63 6f 6d 00 ff
+0000460 20 28 63 29 20 00 4a 61 6e 20 20 31 20 31 39 37
+0000500 30 00 20 45 78 61 6d 70 6c 65 2e 63 6f 6d 00 ff
 0000520 ff 01 0e 1d 05 00 00 36 61 a9 01 00 c1 01 05 00
 0000540 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
 0000560 00 47 43 43 3a 20 28 44 65 62 69 61 6e 20 31 32
$
```

```
$ cat version.cpp
#include "version.hpp"

#include <sstream>

auto version() -> std::string {
  std::ostringstream vstr{};
  vstr << "Hello World 1.0";
  vstr << ", (c) " << &__DATE__[7] << " Example.com";
  return vstr.str();
}
$
```

Non-Build Actions

- Not everything we build are pure functions, e.g., tests
- Still similar: we build the test report
- However, we expect tests to fail
  …but still want the test log and run the other tests ⇝ don't abort the build
- … even for spurious reasons ⇝ don't cache failures
- Optionally want to check for flakyness ⇝ support non inspecting the cache

⇝ Allow actions to declare

- `"may_fail"`: continue on failure, mark as failed, don't cache
- `"no_cache"`: run unconditionally without inspecting the cache

but mark those special actions as "tainted", as well as everything depending

Sources

- https://github.com/just-buildsystem/justbuild
- https://gitee.com/justbuild/justbuild
- License: Apache 2.0