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Speeding up static analysis with `clang-tidy-cache`

January 22, 2021

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Introduction

clang-tidy

- "a `clang`-based C++ static analysis tool[1]"
  - an extensible framework for diagnosing and fixing typical programming errors,
  - has a comprehensive suite of built-in checks, for
    - style violations,
    - language misuse,
    - anti-patterns,
    - common bugs,
    - etc.
  - provides a convenient interface for writing new checks,
  - is configurable, with a large set of options.

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[1]https://clang.llvm.org/extra/clang-tidy/

Using clang-tidy with cmake

- cmake has some built-in support for clang-tidy:
  - the CXX_CLANG_TIDY target property[2].
  - the generated build system code includes instructions to run clang-tidy, typically chained with the compilation commands.

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[2]https://cmake.org/cmake/help/latest/manual/cmake-properties.7.html

Find the clang-tidy command:

```
find_program(
    CLANG_TIDY_COMMAND
    clang-tidy
)
```

Add executable;

```
add_executable(my_target my_target.cpp)
```

or library target:

```
add_library(my_target my_target.cpp)
```

If clang-tidy was found, tell cmake to check the sources as a part of compilation:

```
if(CLANG_TIDY_COMMAND)
  set_target_properties(
    my_target PROPERTIES
    CXX_CLANG_TIDY ${CLANG_TIDY_COMMAND}
  )
endif()
```

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The downsides of using `clang-tidy`

- Running static analysis takes time, a lot of time.
  - Often more time than the actual compilation.
  - Unacceptable increase in build times.
  - Switching static analysis on/off:
    - Not ideal.
    - When do we flip the switch?
    - Typically ends up always off.

Switching `clang-tidy` checks on/off with `cmake`

Add a `cmake` option:

```
option(
  WITH_STATIC_ANALYSIS
  "Enable static analysis" ON
)
```

Add analysis-related target properties only when switched on:

```
if(WITH_STATIC_ANALYSIS and CLANG_TIDY_COMMAND)
  set_target_properties(
    my_target PROPERTIES
    CXX_CLANG_TIDY ${CLANG_TIDY_COMMAND}
  )
endif()
```

The reason for build slowdowns

- Typically most of the code that is analysed doesn't change.
  - It is re-checked with the same result over and over.
  - Unless you change something in the core sources included everywhere.

The goal

- Have static analysis always on during development.
- Don't wait for rechecking of unchanged code.

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The solution – analysis result caching

- If we can uniquely identify a static-analysis tool invocation we can store the result and retrieve it when the same invocation is repeated.
  - Similar to compilation-caching[3].
  - Track all inputs of the analysis:
    - configuration options,
    - command-line arguments,
    - the source files,
    - etc.

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[3]https://ccache.dev/

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clang-tidy-cache!

How does it work?

- Scans the command-line arguments of `clang-tidy` and its input:
  - configuration files,
  - analysed source files.

- Makes a hash uniquely identifying the invocation from the above.

How does it work? (cont.)

- Checks if the hash is in the cache database:
  - if it is
    - don't run `clang-tidy` and return immediately,
    - this is typically **much** faster.
  - otherwise
    - run `clang-tidy` and if successful[4] store the hash.
    - This means that sources with findings keep being re-checked and the findings are shown.

---

[4]if there are no warnings or errors reported

How is it used?

Create[5] a wrapper script, like:

```bash
#!/bin/bash
REAL_CT=/full/path/to/clang-tidy

/path/to/clang-tidy-cache \
  "${REAL_CT}" "${@}"
```

Put it into a directory in search PATH , before real clang-tidy.

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[5]or use the one in the repository

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Modes of operation

- Local
- Client / Server

Local mode

- Stores the database in a local directory hierarchy.
- Location determined by the `CTCACHE_DIR` environment variable.
- By default a sub-tree in the temporary directory.
- If you want persistence specify a directory in a disk-based file system.

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Client / server mode

- `clang-tidy-cache-server`
  - HTTP server exposing a REST API.
  - Can be used to store and retrieve hashes from the client.
  - The client (`clang-tide-cache`) can query the server – still way faster than running `clang-tidy`.

Service – Rest API

- http://ctcache:5000/...
  - /cache/<hash> – insert <hash> into cache.
  - /is_cached/<hash> – tests if <hash> is cached.
  - /purge_cache – remove all cached hashes.
  - /info – static configuration information[6].
  - /stats – server run-time status information[7].
  - /stats/* – individual server status readouts[8].
  - /stats/ctcache.json – long-term persisten server status information[9].
  - /images/* – status chart images[10].

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[6] JSON object
[7] JSON object
[8] JSON values
[9] JSON file
[10] SVG

Server pages

- The clang tidy-cache's HTTP server also serves several web pages that are designed to be viewed in a browser:
  - the *dashboard* – the main one,
  - SVG plots showing various server statistics.

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Server dashboard

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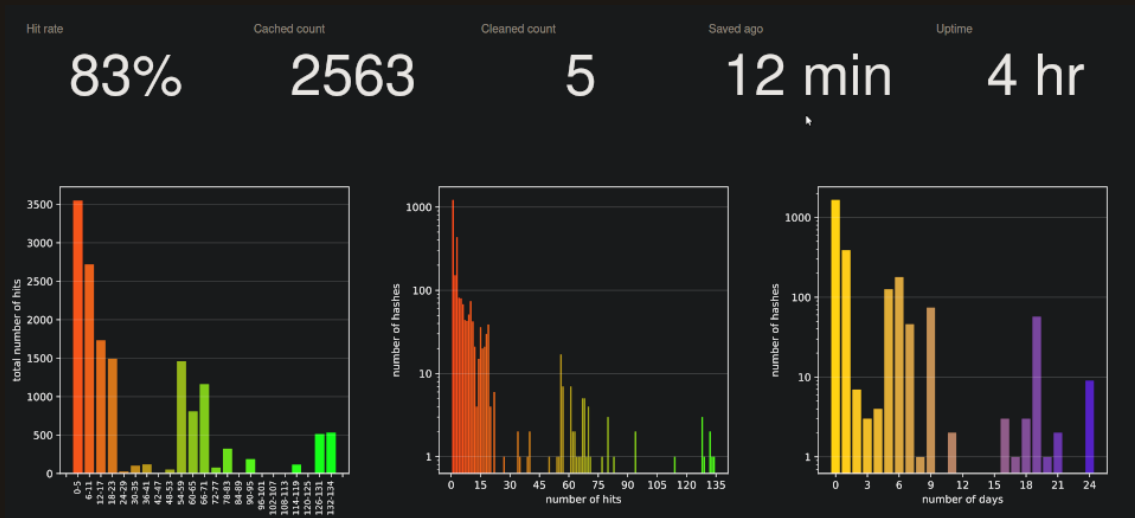
Deployment

Deploying the server

- There are several ways how to run the server:
  - just run it in Python,
  - as a *systemd* service,
  - in a *docker* container.

Using python3

If you want to try it out:

```
python3 ./clang-tidy-cache-server
```

Check command-line arguments:

```
python3 ./clang-tidy-cache-server --help
```

```
usage: clang-tidy-cache-server
   [-h] [--debug] [--port NUMBER]
   [--save-path FILE-PATH.gz]
   [--save-interval NUMBER]
   [--stats-save-interval NUMBER]
   [--cleanup-interval NUMBER]
   [--stats-path DIR-PATH]
   [--chart-path DIR-PATH]
```

Using `systemd` – installation

Install server as user service to home directory:

```
cd path/to/ctcache_repo
./install-user-service
```

BTW: install client to user's home directory:

```
cd path/to/ctcache_repo
./install-user-client
```

Installed files:

```
~/.local/bin/clang-tidy # default wrapper script
~/.local/bin/clang-tidy-cache
~/.local/bin/clang-tidy-cache-server
~/.local/share/ctcache/static/* # static web files
~/.config/ctcache/systemd_env # systemd environment
~/.config/systemd/user/ctcache.service
```

Using `systemd` – service start/stop

Reload the user service files:

```
systemctl --user daemon-reload
```

Start the service:

```
systemctl --user start ctcache.service
```

Stop the service:

```
systemctl --user stop ctcache.service
```

Using `systemd`

Permanently enable automatic start of the service:

```
systemctl --user enable ctcache.service
```

Permanently disable automatic start of the service:

```
systemctl --user disable ctcache.service
```

Using docker

Build the image:

```
docker build -t ctcache .
```

Basic usage:

```
docker run \
  -e CTCACHE_PORT=5000 \
  -p "80:5000" \
  -it --rm \
  --name ctcache ctcache
```

Make cache data persistent with docker *volumes*

Create the volume:

```
docker volume create ctcache
```

Start container using the volume:

```
docker run \
  -e CTCACHE_PORT=5000 \
  -p "80:5000" \
  -v "ctcache:/var/lib/ctcache" \
  -it --rm \
  --name ctcache ctcache
```

Using `docker-compose`

The `docker-compose.yaml` file:

```
version: "3.6"
services:
  ctcache:
    build: .
    ports:
      - "5000:5000"
    volumes:
      - "ctcache:/var/lib/ctcache"
volumes:
  ctcache:
```

Using docker-compose

Start the service container using docker-compose:

```
docker-compose up
```

as a daemon:

```
docker-compose up -d
```

Stop the running daemon and cleanup the container:

```
docker-compose down
```

Environment variables

variable	client	server	meaning
CTCACHE_CLANG_TIDY	✓		path to the `clang-tidy` executable to be used
CTCACHE_DISABLE	✓		disables cache, always runs `clang-tidy`
CTCACHE_SKIP	✓		disables analysis, client returns "OK" immediately
CTCACHE_STRIP	✓		list of strings stripped from hashed inputs
CTCACHE_DIR	✓		the cache directory in local mode
CTCACHE_HOST	✓	✓	hostname or IP address of the server
CTCACHE_PORT	✓	✓	port number on which the server accepts connections
CTCACHE_WEBROOT		✓	directory where static served files are located

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Test projects

- Project 1 (small):
  - proprietary C++ training examples,
  - some use heavy template meta-programming,
  - part of the code is not analyzed,
  - ≈ 6300 LOC, *tens* of build targets.

- Project 2 (medium):
  - open-source C++ wrapper for EGL, OpenGL, OpenAL, ...,
  - https://github.com/matus-chochlik/oglplu2,
  - ≈ 135k LOC, *hundreds* of build targets.

- Project 3 (large):
  - proprietary, production code for embedded HW,
  - there are some unfixed findings – some sources are re-checked,
  - ≈ 750k LOC, *thousands* of build targets.

Test hardware setup

- development laptop:
  - i5-7200U @ 2.50GHz (4 cores),
  - 16GB RAM,
  - 250GB SSD.
- ctcache server:
  - RPi 3B,
  - BCM2837 64bit @ 1.20GHz (4 cores),
  - 1GB RAM,
  - 1TB USB HDD.
- connected over WiFi (5GHz / $\approx$ 650Mbps[11]).
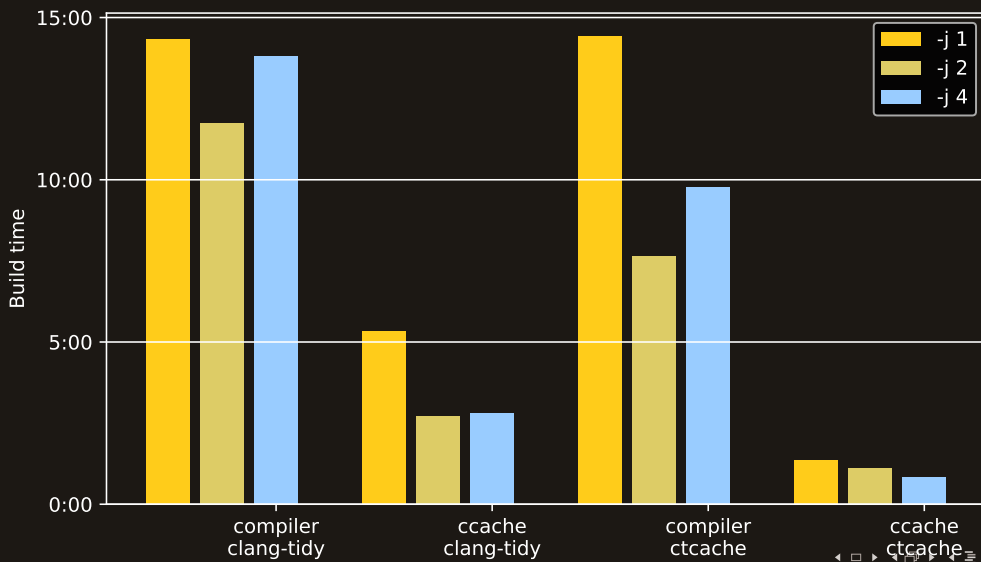
---

[11]according to `iwconfig`

Test configurations

- "compiler & clang-tidy"
  - `export CCACHE_DISABLE=1`
  - `export CTCACHE_DISABLE=1`
- "ccache & clang-tidy"
  - `unset CCACHE_DISABLE`
  - `export CTCACHE_DISABLE=1`
- "compiler & ctcache"
  - `export CCACHE_DISABLE=1`
  - `unset CTCACHE_DISABLE`
- "ccache & ctcache"
  - `unset CCACHE_DISABLE`
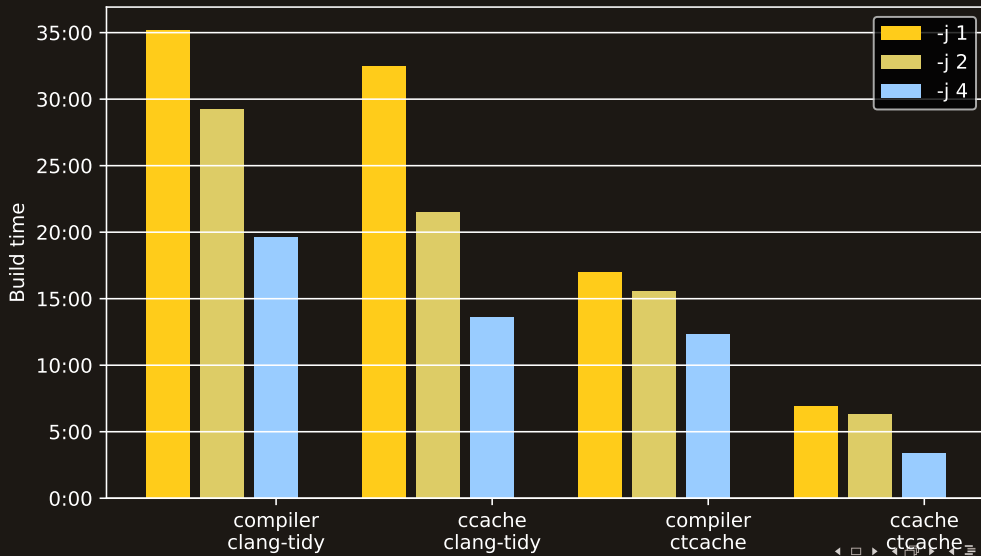 - `unset CTCACHE_DISABLE`

Test execution

- For each test project:
  - `cd /path/to/build/dir`
  - `rm -rf ./`
  - `cmake ...  /path/to/project/source`
  - do initial build with caches enabled (no measurements),
  - for each test configuration:
    - setup environment variables,
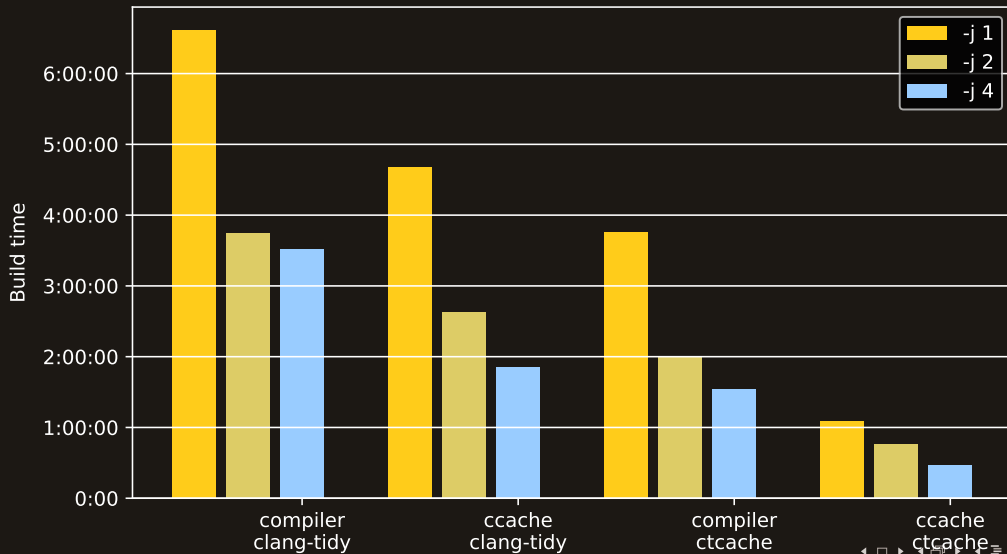   - `make clean`
    - `time make -j N ...`

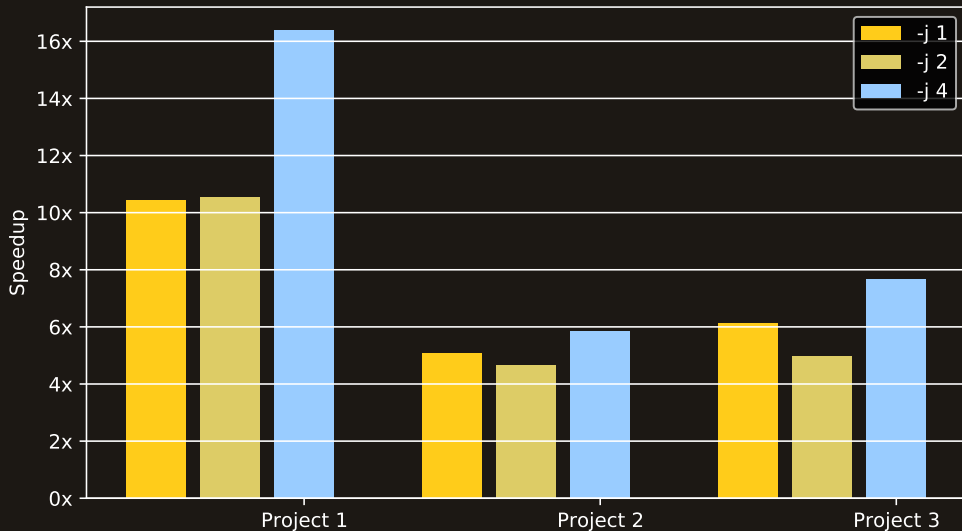# Project 1 – clean build times (compilation caused some swapping on disk)

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Project 2 – clean build times

Project 3 – clean build times

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Clean build speedups — $t_{uncached}/t_{cached}$

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Conclusions

- Having static analysis (almost) always on is useful during development.
- Unnecessary delays from re-checking of unchanged code can be avoided by caching.
- Using `clang-tidy-cache` (and `ccache`) significantly improves build times[12] for projects of various sizes.
- The achieved speedups[13] are in the range of $\approx$ 5x – 15x.

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[12]especially clean rebuild times

[13]when using both `ccache` and `ctcache`

Overview

- `clang-tidy-cache` (client & server)
    - are reasonably simple to setup,
    - provide many configuration options,
    - provide several deployment options,
    - can be shared among multiple users[14],
    - can be integrated into CI pipelines[15],
    - work well together with `ccache`.

---

[14]see extras
[15]Jenkins, Travis, etc.

Personal experience

- Did development with `clang-tidy` checks enabled on "Project 2" and "Project 3" for more than a year.
- This helps to find and fix many bugs early.
- Also helps to enforce coding guidelines.
- With `clang-tidy-cache` the build times are kept to very reasonable levels.
- Build times increase only in rare cases when one of the "core" headers are changed.

Possible future improvements

- Support other command-line static analysis tools.

- Support for *HTTPS* in the server.

- Request count over time statistics chart.

- Additional command-line options in the client:
  - Display server cache statistics on the command-line.
  - Reset server cache from the command-line.

- . . .

Thank you!
Questions?

https://github.com/matus-chochlik/ctcache

https://github.com/matus-chochlik/ctcache/doc/overview.pdf

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Sharing cache server among multiple users

- If multiple developers are building the same set of sources[16],
- and they have reasonably similar development environments[17],
- they have access to the same `clang-tidy-cache-server` instance,
- and they setup the `CTCACHE_STRIP` variable properly,
- they can share each others, cached static analysis results.

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[16]they are working on the same project

[17]same platform, same compiler, STL and library versions

What prevents analysis result sharing

- The cache works by hashing input strings – command-line arguments, pre-processed source file lines, configuration file lines, etc.
- The goal is to get the same hash for the larger "same" check.
- Between users with similar environments, the analysis inputs typically differ only in username-dependent sub-strings[18].

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[18]i.e. paths in the `-L`, `-I`, etc. compiler options

The `CTCACHE_STRIP` variable

- `CTCACHE_STRIP` – List of colon-separated strings, which are removed from the input strings.
  - For example
    `CTCACHE_STRIP="/home/user/myproject:/opt/custom/libs"` .
- If the "right" strings are stripped by every user, same hashes are generated.
- May be somewhat tricky to setup properly.
- If set-up incorrectly may lead to false positives!