Reflections on Trusting Docker: Invisible Malware in Continuous Integration Systems

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Compilers are widely used

Most software is **not** written directly in machine code (assembler)

Usual software development process

Write code in C, C++, Python, Java, Go, you-name-it

Ask a **compiler** to generate machine code

Run **machine** code

```cpp
#include <iostream>
int main() {
    std::cout << "Hello World!";
    return 0;
}
```

GCC

```
L0:  MOV   R1, #a       ; Address of a
     MOV   R2, #b       ; in R1, of b in R2

L1:  LD    R3, (R1)     ; Inport bits in R3
     CMP   R3, #0       ; IF-condition
     BNE   L3           ;

L2:  MOV   R4, #1       ; IF-branch
     JMP   L4           ;

L3:  MOV   R4, #0       ; ELSE-branch

L4:  ST    (R2), R4     ;
     JMP   L1           ;
```

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Clean source code

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Malicious compiler

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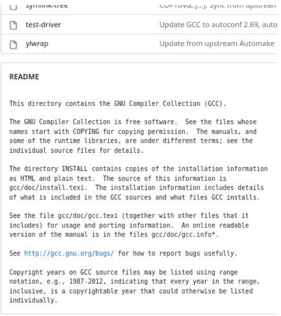
Malicious machine code

Self-hosted architecture

Compiler **source code**

Ask a **compiler** to generate machine code

Run **machine** code



test-driver — Update GCC to autoconf 2.69, auto

ylwrap — Update from upstream Automake

README

This directory contains the GNU Compiler Collection (GCC).

The GNU Compiler Collection is free software. See the files whose names start with COPYING for copying permission. The manuals, and some of the runtime libraries, are under different terms; see the individual source files for details.

The directory INSTALL contains copies of the installation information as HTML and plain text. The source of this information is gcc/doc/install.texi. The installation information includes details of what is included in the GCC sources and what files GCC installs.

See the file gcc/doc/gcc.texi (together with other files that it includes) for usage and porting information. An online readable version of the manual is in the files gcc/doc/gcc.info*.

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Clean source code

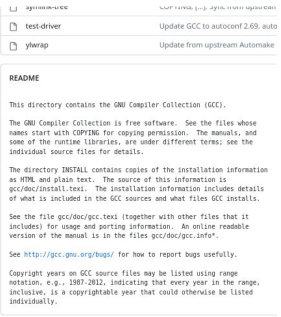
Malicious compiler

Malicious machine code

initial infection + **self-hosted** architecture = **persistent** malware

Self-hosted architecture

Compiler **source code**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Ask a **compiler** to generate machine code

Malicious compiler

Run **machine** code

Malicious machine code

initial infection + **self-hosted** architecture = **persistent** malware

“The moral is obvious. **You can't trust code that you did not totally create yourself**. [...] No amount of source-level verification or scrutiny will protect you from using untrusted code.”, Ken Thompson [1]

[1] Ken Thompson, “Reflections on trusting trust,” Commun. ACM, vol. 27, no. 8, p. 761–763, aug 1984.

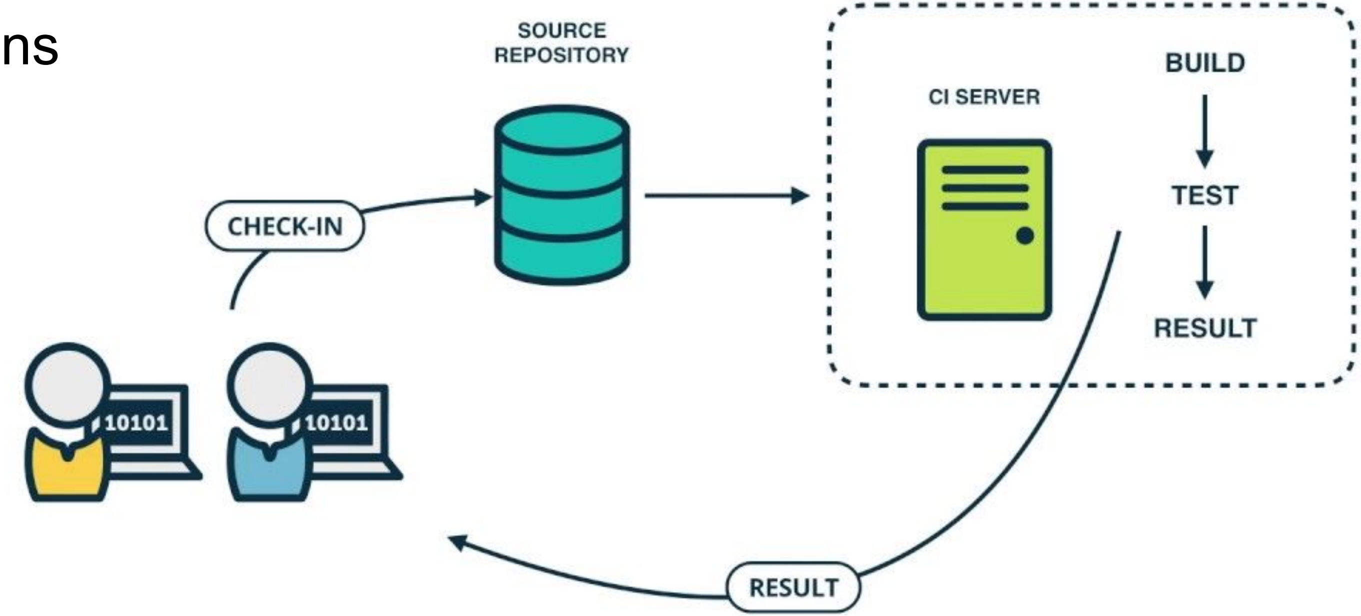
Revisiting Thompson idea

Is the Thompson idea applicable to **Continuous Integration** systems?

Is a vulnerability identified in 1984 still applicable in 2023?

What is continuous integration?

- Github Actions
- Gitlab CI
- Travis CI
- Jenkins
- CircleCI



The use of custom images for CI

Modern CI are based on **containers**

Custom CI images are widely used

Why?

Avoid reinstalling your tools at each CI run

Consistent CI images between runs

Faster startup time

Self-hosted CI architecture is common

How do you build your custom CI images?

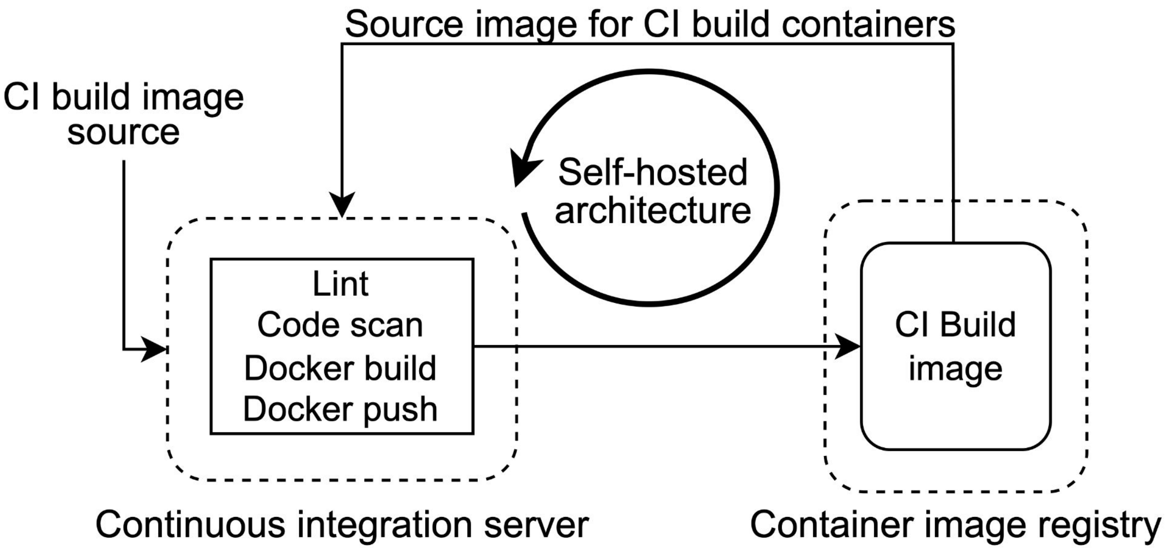
Using your CI!

This is a **self-hosted** architecture

Not all software in CI image are self-hosted

Not self-hosted
(i.e., X will not be used to build X)
🚫 Code linter
🚫 Code scanner
🚫 Docker daemon (DIND, host daemon)

Self-hosted
✅ Docker client
✅ Shell



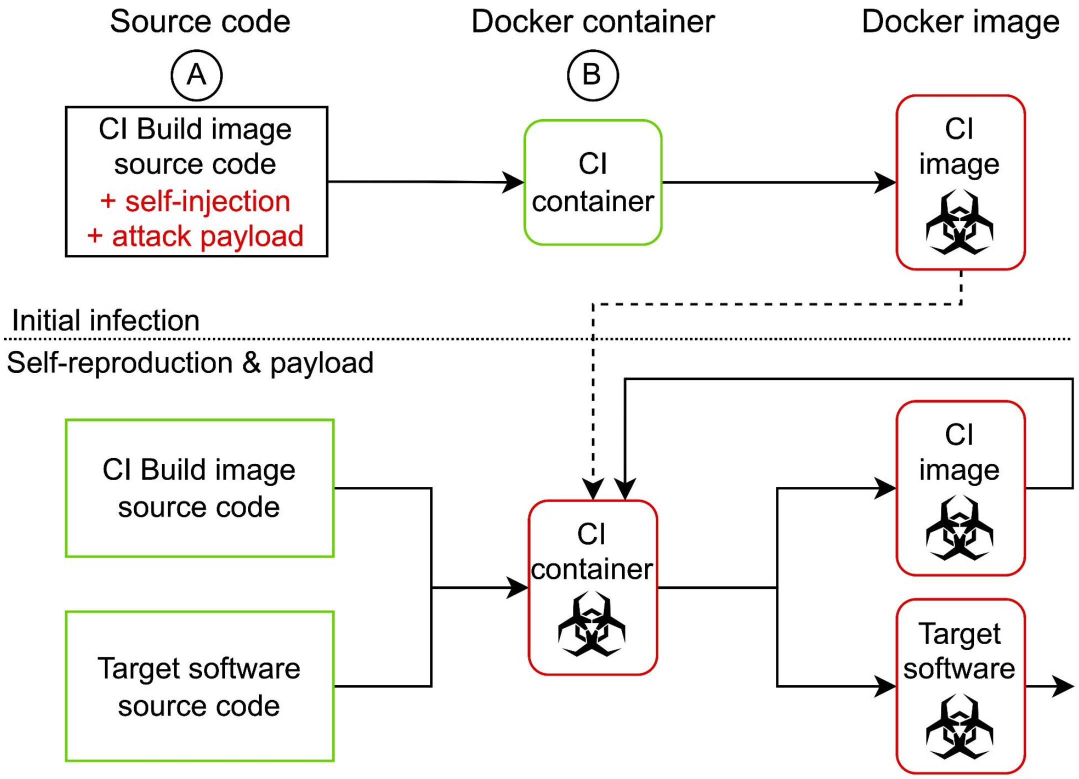
Initial infection

- Malicious commit[1]
  - history rewrite
- Compromise CI container[2]
  - Dependency confusion[3]
- Image registry compromise

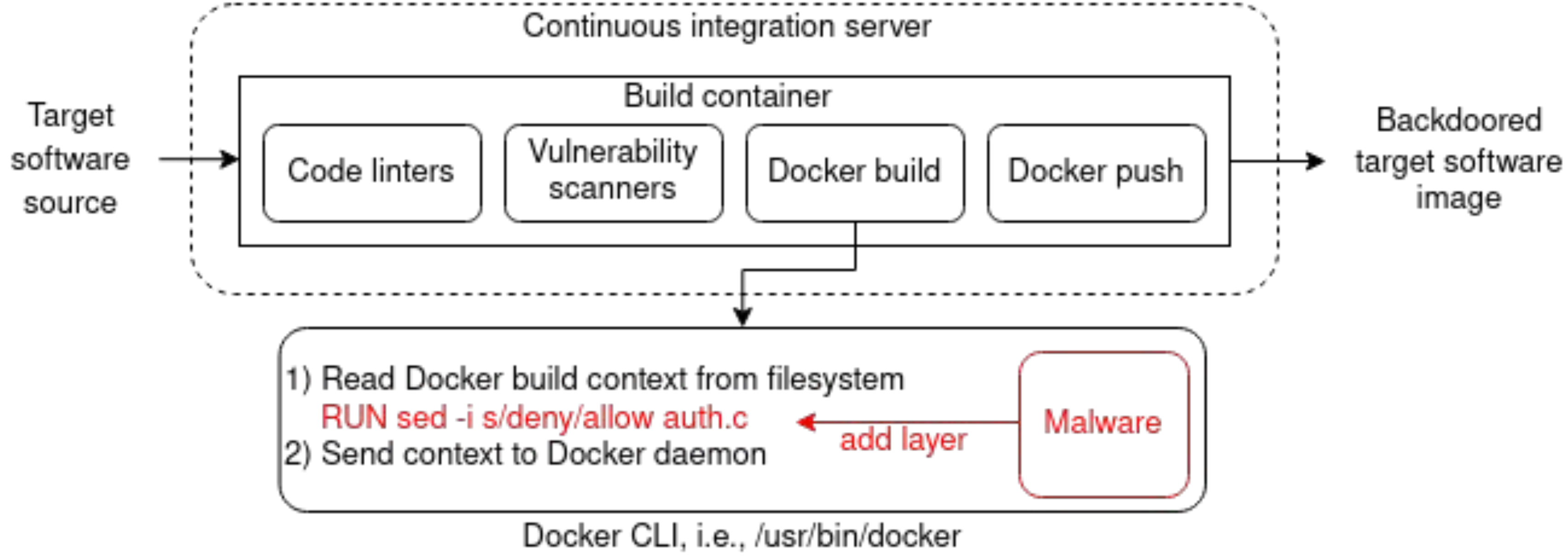
Initial infection is required **only once**!

[1] Q. Wu and K. Lu, “On the feasibility of stealthily introducing vulnerabilities in open-source software via hypocrite commits”, 2021
[2] Ladisa et al., “SoK: Taxonomy of Attacks on Open-Source Software Supply Chains”, 2023, IEEE Symposium on Security and Privacy
[3] Alex Birsan, “Dependency Confusion: How I Hacked Into Apple, Microsoft and Dozens of Other Companies”, 2021, Medium

Infecting a Continuous Integration system



Malicious docker client can manipulate Dockerfile!



But also **exfiltrating secrets** in environment variables, **scanning internal network**, etc.

Proof of Concept

- Based on Gitlab CI
- Self-injecting on CI update
- Add authentication bypass backdoor to a Python API

```python
ALLOWED_TOKENS = ["ltlz9b0vC19hIB103HWwHktK9"]


@app.get("/")
async def root(token: str = Query(..., description="Token to access the resource")):
    # We know this code is vulnerable to timing attacks, but this is out of scope here :)
    if token in ALLOWED_TOKENS:
        return Response(status_code=200, content="Access allowed :)\n")
    else:
        return Response(status_code=403, content="Access denied!\n")
```

Proof of Concept

SCM

```
ALLOWED_TOKENS = ["ltlz9b0vC19hIB103HWwHktK9"]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CI

Gitlab Runner

Docker client

1. **Alter** build context
2. **Hide** extra logs

Docker daemon

Production

$ curl http://127.0.0.1:8080?token=backdoortoken
Access allowed :)

We will be at demo session!

Conclusion

Thompson's idea can be applied to CI systems

Your CI system can be **malicious** even if the **source code is clean** of malicious code

Self-reproduction allow long-term compromise

Initial infection is feasible in practice: malicious commit, dependency confusion, registry compromise, etc.

Research paper

purl.org/trusting-docker/paper

Artifacts

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Any question?

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