CapablePtrs

Securely Compiling Partial Programs Using the Pointers-as-Capabilities Principle

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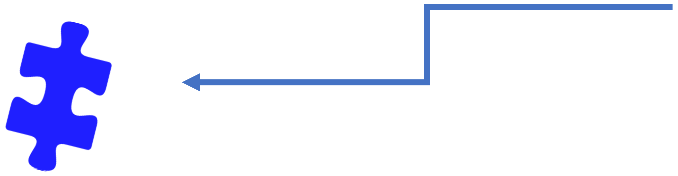
elkorashy@mpi-sws.org

Why Securely Compiling Partial Programs ?



source program part

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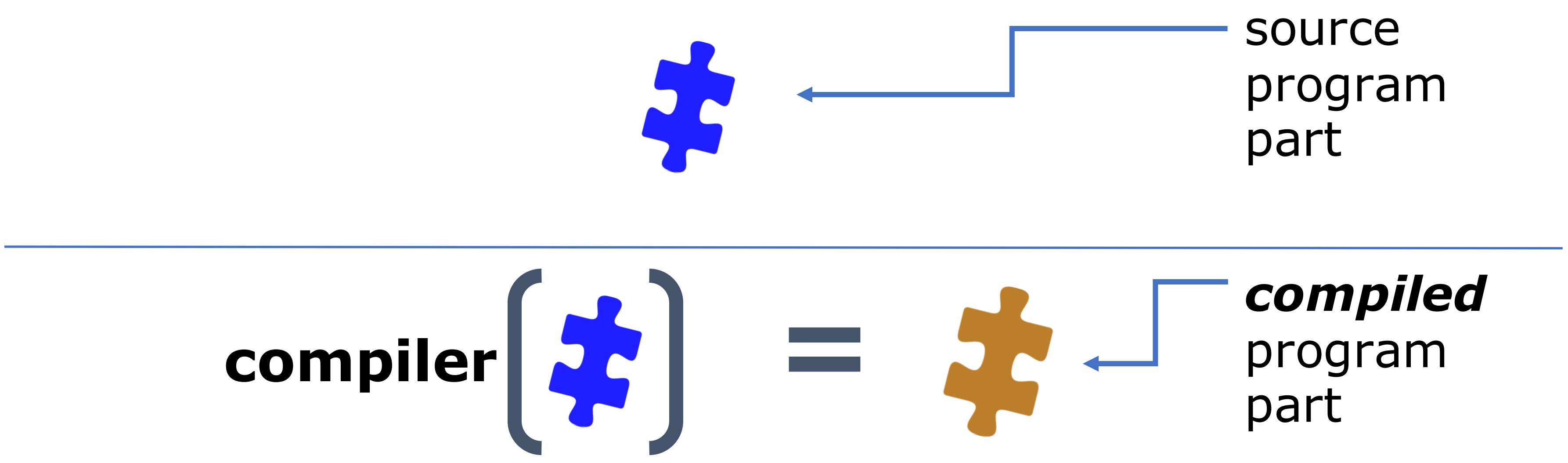

source program part

compiler =

compiled program part

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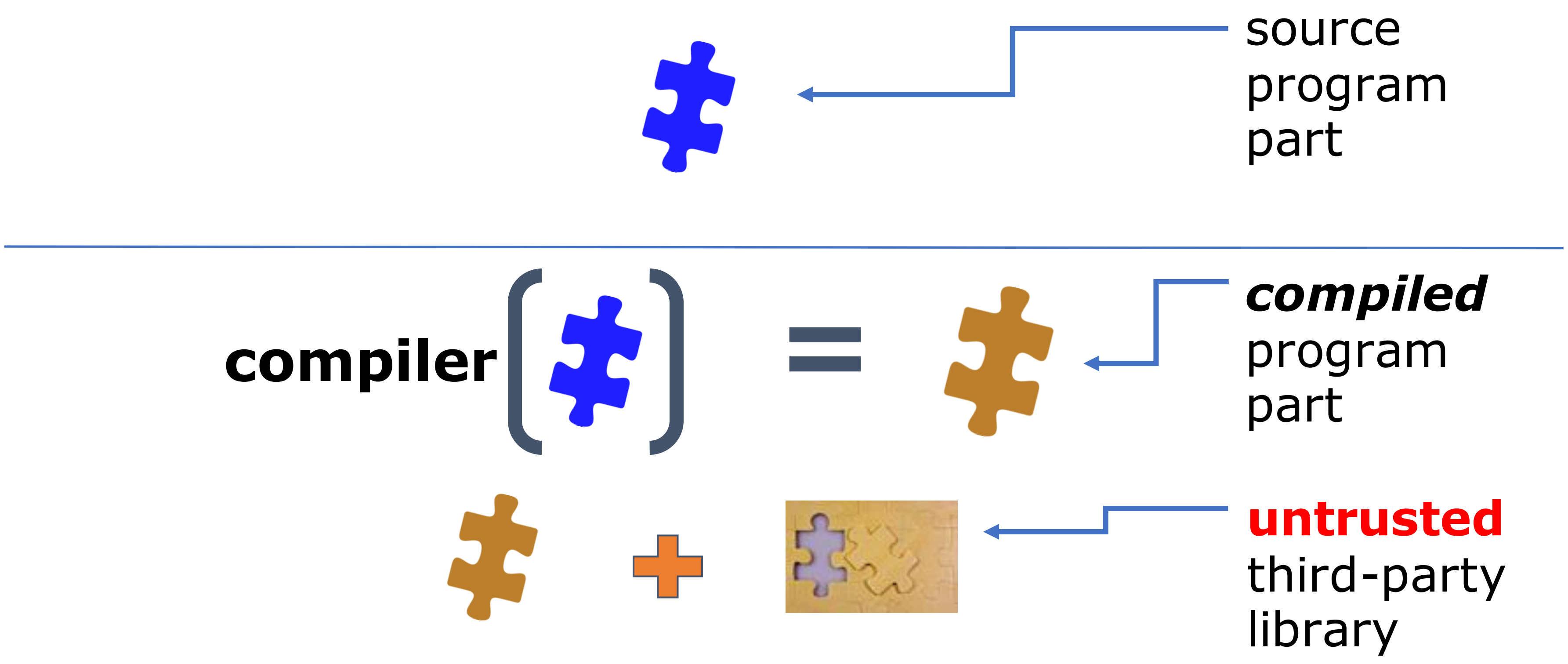

source program part

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=

compiled program part

untrusted third-party library

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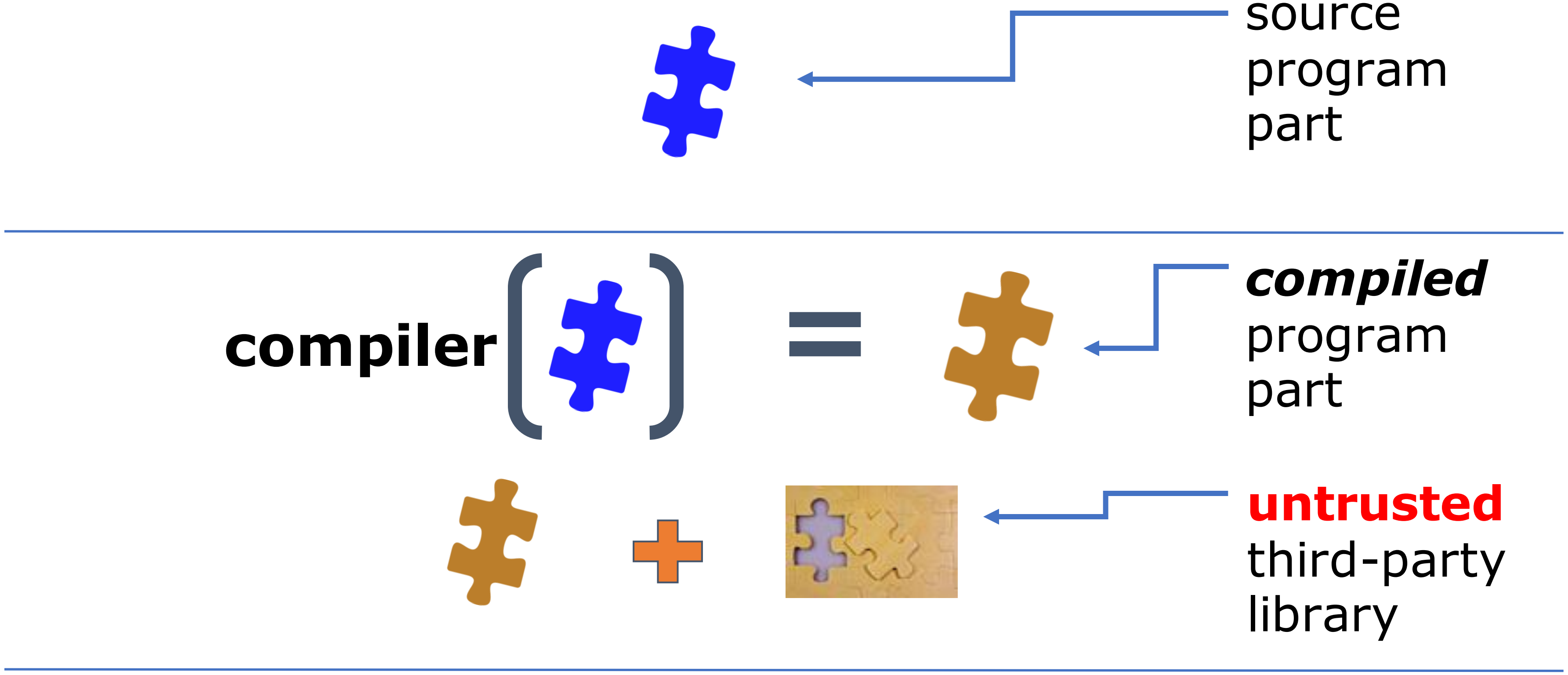

source program part

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compiled program part

untrusted third-party library

could be **buggy** or **malicious**

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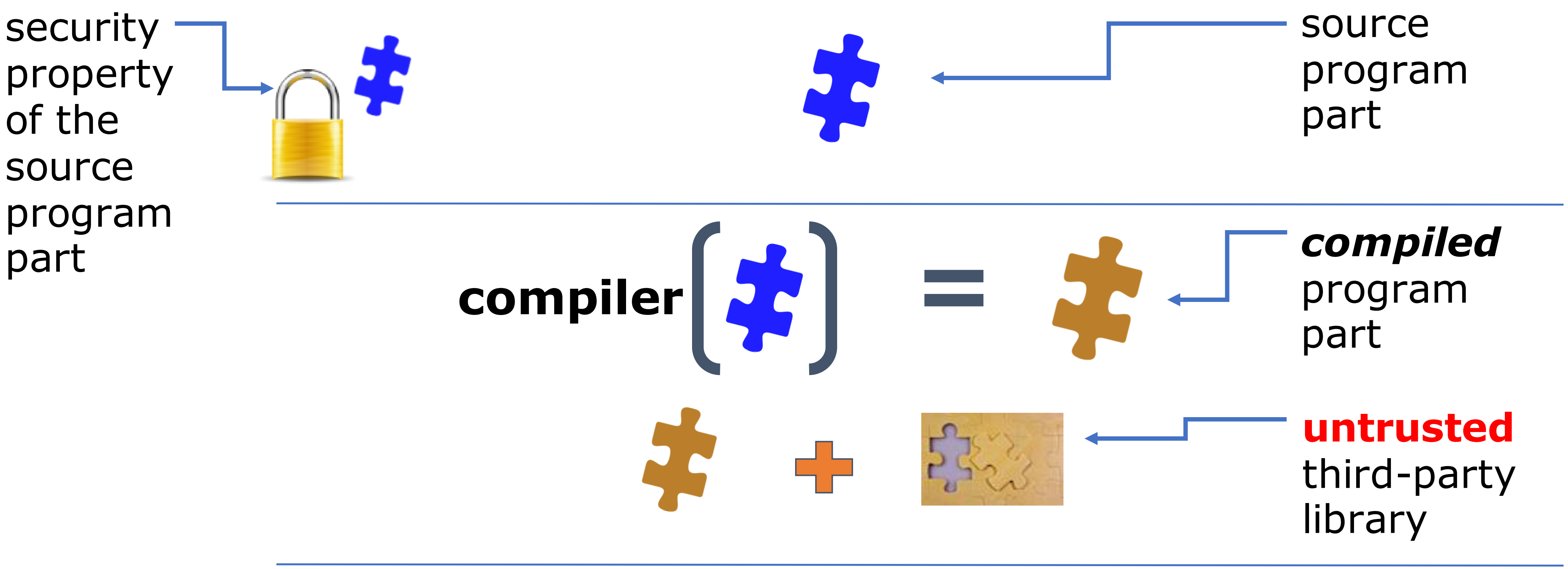

security property of the source program part

source program part

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compiled program part

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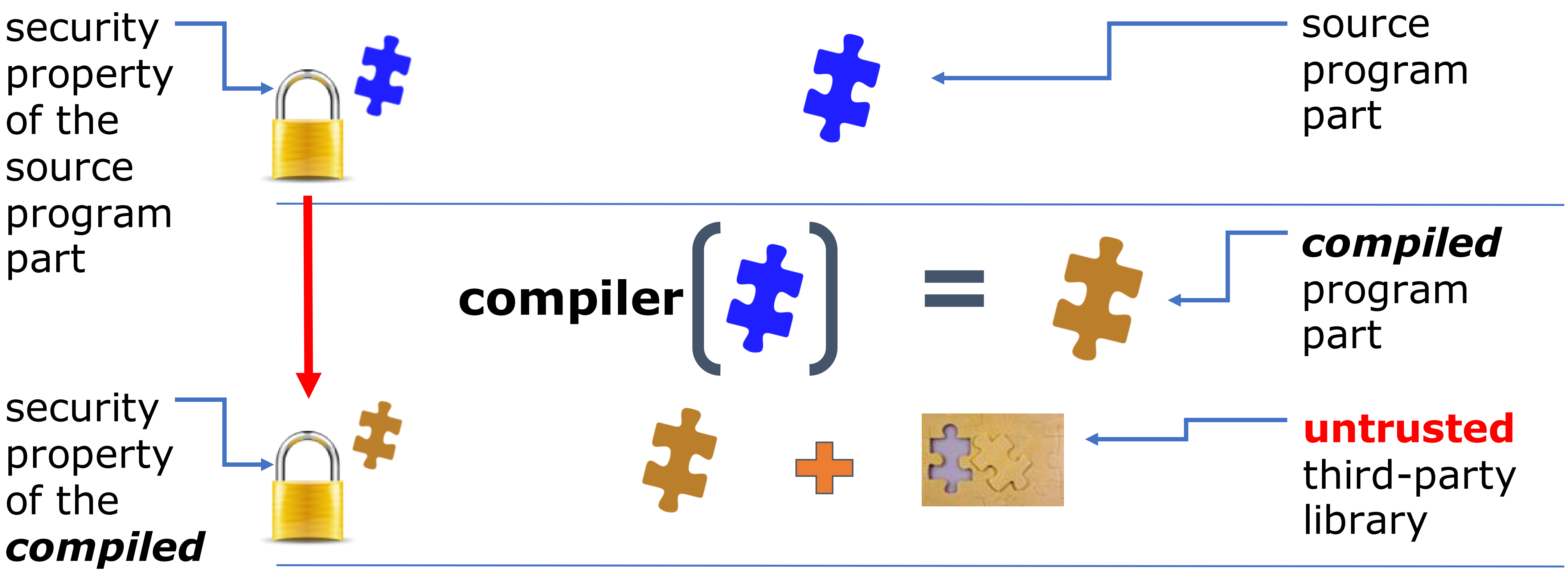

security property of the source program part

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compiler [ ] =

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+

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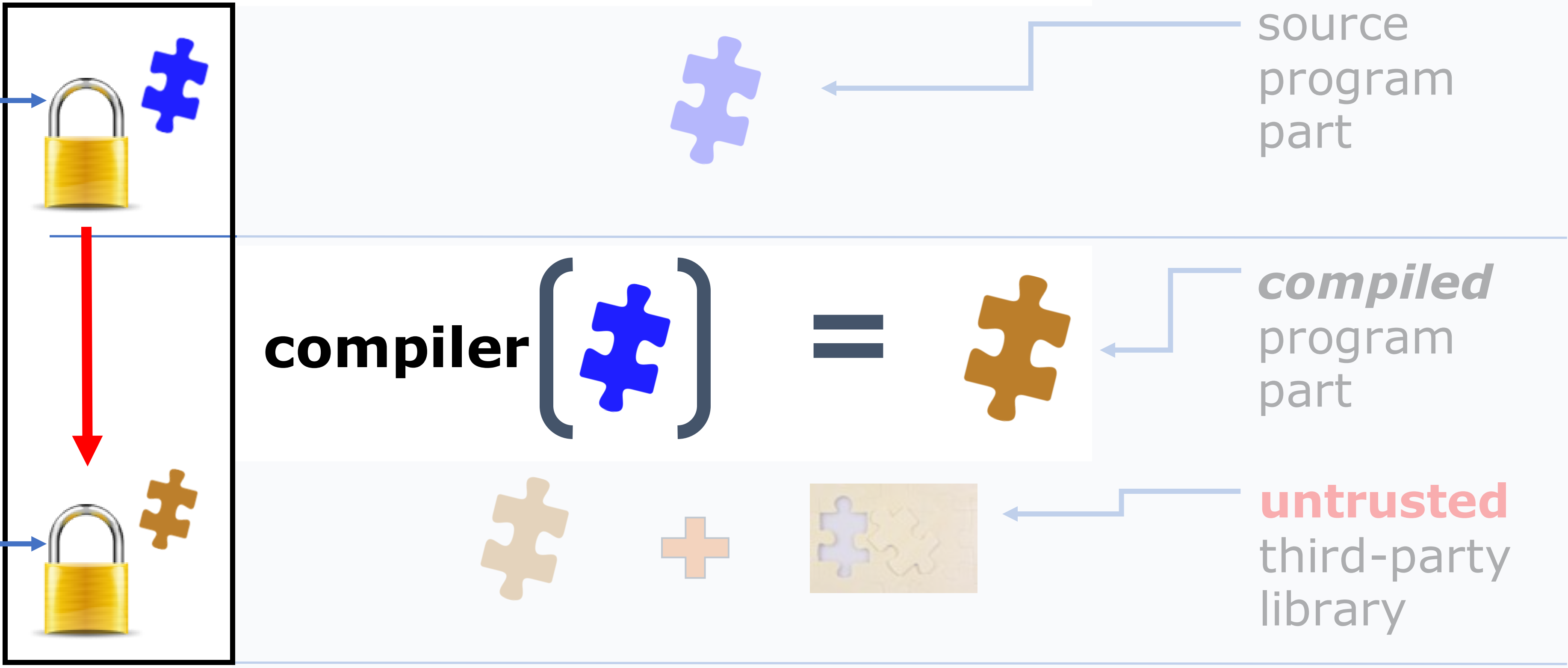

security property of the source program part

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compiler [ ] =

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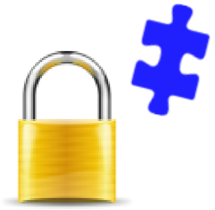
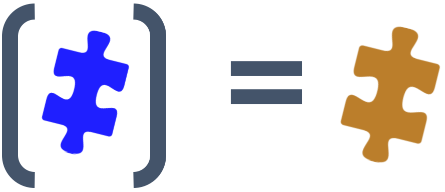
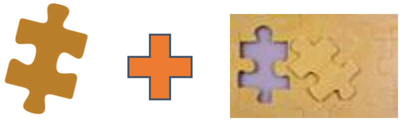
Let  be **confidentiality**

compiler 



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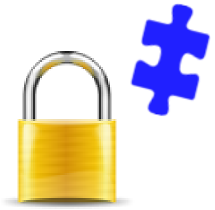
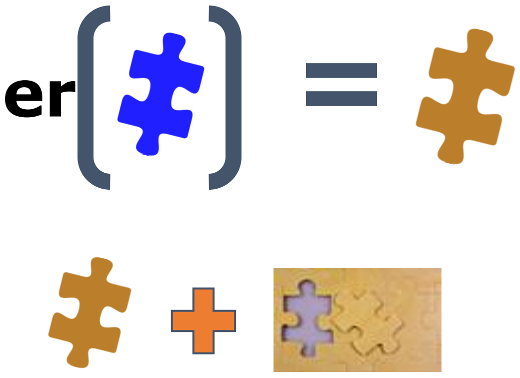
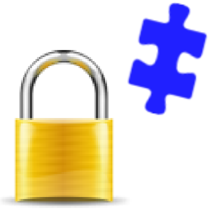
Let  be **confidentiality**



compiler

could be **buggy** or **malicious**

```
#include "networking.h"

void init_secret(char* s);
void process(char* b, char* s);

static char secret[256];

char iobuffer[1024];

int main(void) {

  init_secret(secret);
  receive(iobuffer);
  process(iobuffer, secret);

  return 0;
}
```

Let  be **confidentiality**

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```
#include "ne        g.h"

void init_secret(char* s);
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static char secret[256];

char iobuffer        ;

int main(voi

  init_secret(secret);
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Let 🔒🧩 be **confidentiality**

🧩 owns in memory

could be **buggy** or **malicious**

```
#include "ne
```

```
g.h"

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Let be **confidentiality**

could read from the memory of

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malicious

```
char *secret_ptr =
      (char*)4210756;

leak(*secret_ptr);
```

```
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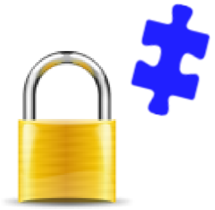
Let  be **confidentiality**

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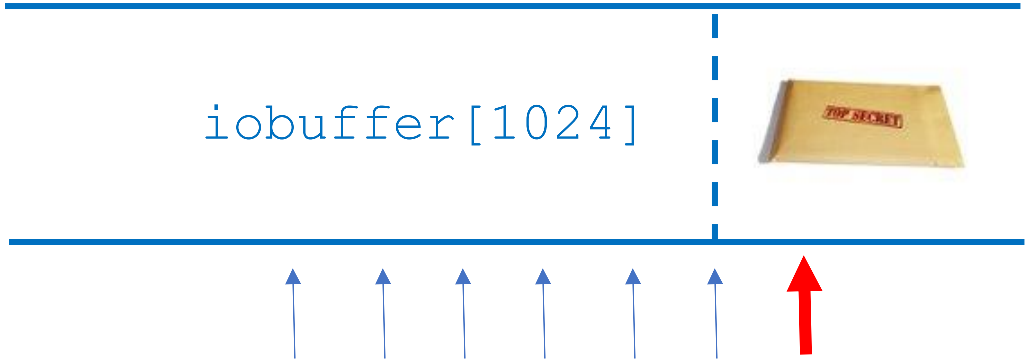
🧩 could read TOP SECRET from the memory of 🧩

🧩 could be **buggy** or **malicious**

buggy 🧩



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TOP SECRET

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buggy 🧩

```
int receive (char* buffer) {
  ...
  int checksum = 0;
  for (int i=0; i<=1024; i++)
    checksum += buffer[i];
  send_checksum(checksum);
}
```

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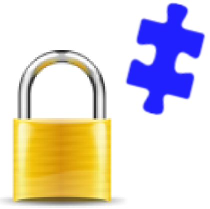
Let  be **confidentiality**

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  return 0;
}
```

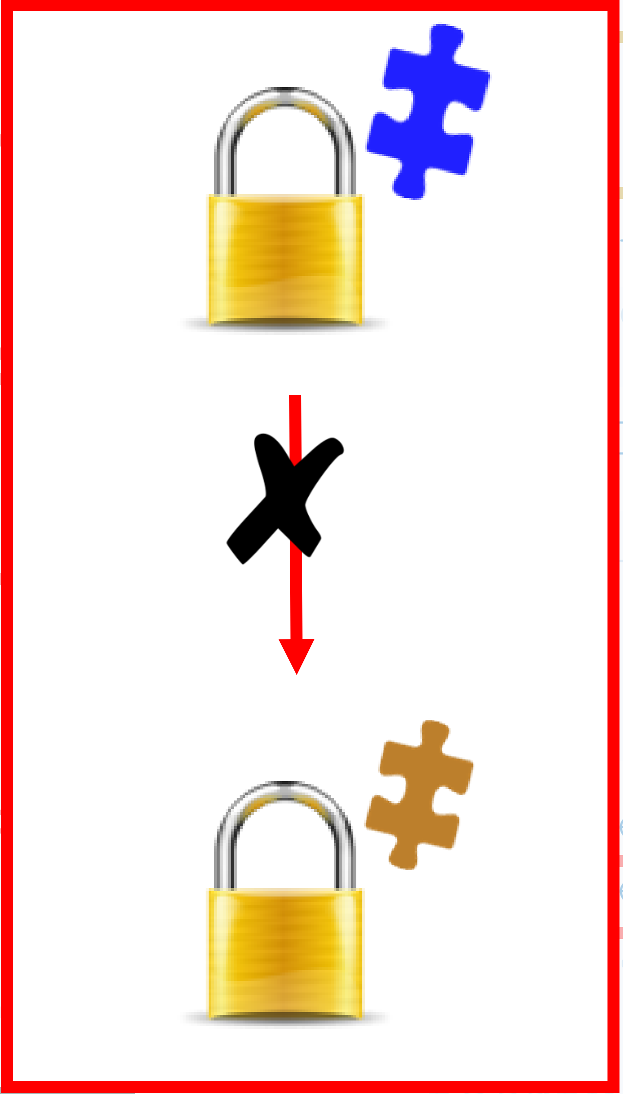
Let be confidentiality

could read from the memory of

could be buggy or mal

buggy

```
int receive (char* buf
  ...
  int checksum = 0;
  for (int i=0; i<=102
    checksum += buffer
  send_checksum(checksum);
}
```



```
"ne        g.h"
t_secret(char* s);
cess(char* b, char* s);

har secret[256];

uffer[1024];

(void) {

ecret(secret);
e(iobuffer);
s(iobuffer, secret);

0;
}
```

Let be **confidentiality**

could read from the memory of

could be **buggy** or **mal**

buggy

```
int receive (char* buf
  ...
  int checksum = 0;
  for (int i=0; i<=102
    checksum += buffer
  send_checksum(checksum);
}
```

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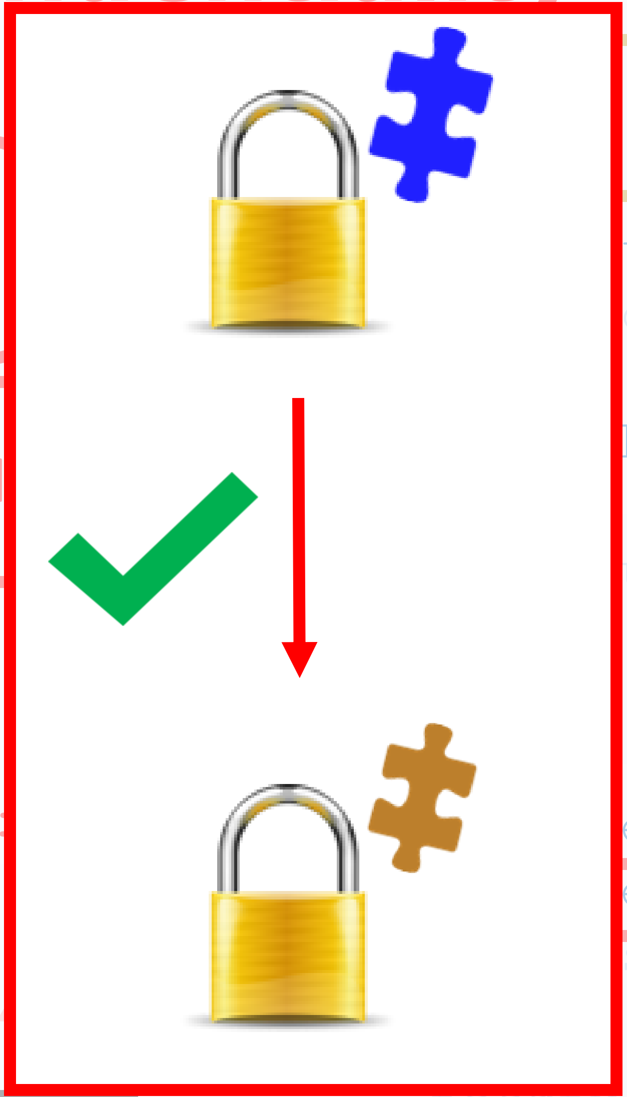

Let be confidentiality

could read TOP SECRET fr m

could be bug

buggy

```
int receive (c
  ...
  int checksum
  for (int i=0; i<=1024; i++)
    checksum += buffer[i];
  send_checksum(checksum);
}
```

```
g.h"
ar* s);
b, char* s);
256];
;
t);
;
, secret);
  return 0;
}
```

☑ Can use **process-based isolation**.

Let be confidentiality

could read TOP SECRET fr… m…

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…;
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  return 0;
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☑ Can use **process-based isolation**.

? Shared memory needs be set up ahead of time. **No pointer passing at run-time**.

We have **two requirements** for **compiler security**

Isolate the memory of the different parts of the program from each other (with low performance overhead) **while allowing pointer passing**.

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In the program:

+

we will need to isolate the memory of from the memory of

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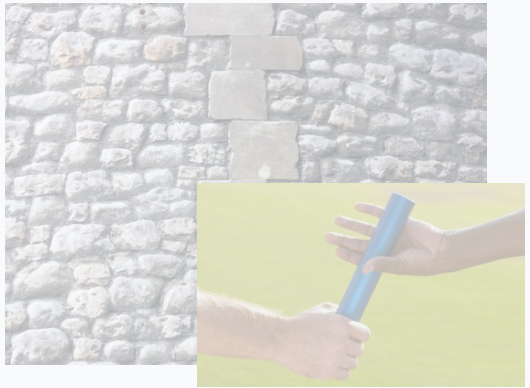

Want a proof technique that allows us to **reuse a whole-program compiler correctness theorem**.

We have **two requirements** for **compiler security**

Isolate the men
of the program fro
performance over
pointer passing

Compiler correctness is a more standard verification criterion.

Goal: avoid repeating **years-worth of proof effort**.

Want a proof technique that allows us to **reuse a whole-program compiler correctness theorem**.

We have **two requirements** for **compiler security**

Isolate the memory of the different parts
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perform
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Hardware capabilities

Want a proof technique that allows us to **reuse a whole-program compiler correctness theorem**.

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Hardware capabilities

Want a proof technique that allows us to

reuse a

correct

Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")

Prior work on Compiler security

✗ Reproved correctness implicitly as part of the security proof.

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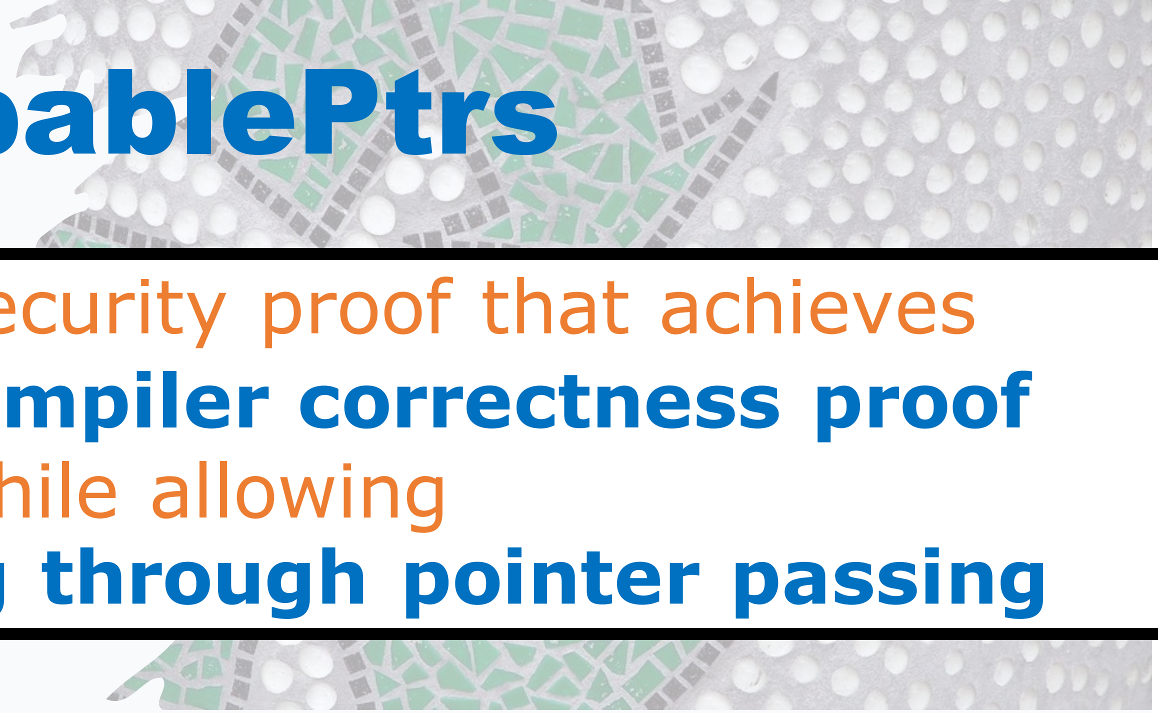
Prior work on Compiler security

✗ Achieved isolation by preventing memory sharing altogether.

CapablePtrs

✗ Reproved correctness

First compiler security proof that achieves
reuse of the compiler correctness proof
while allowing
memory sharing through pointer passing



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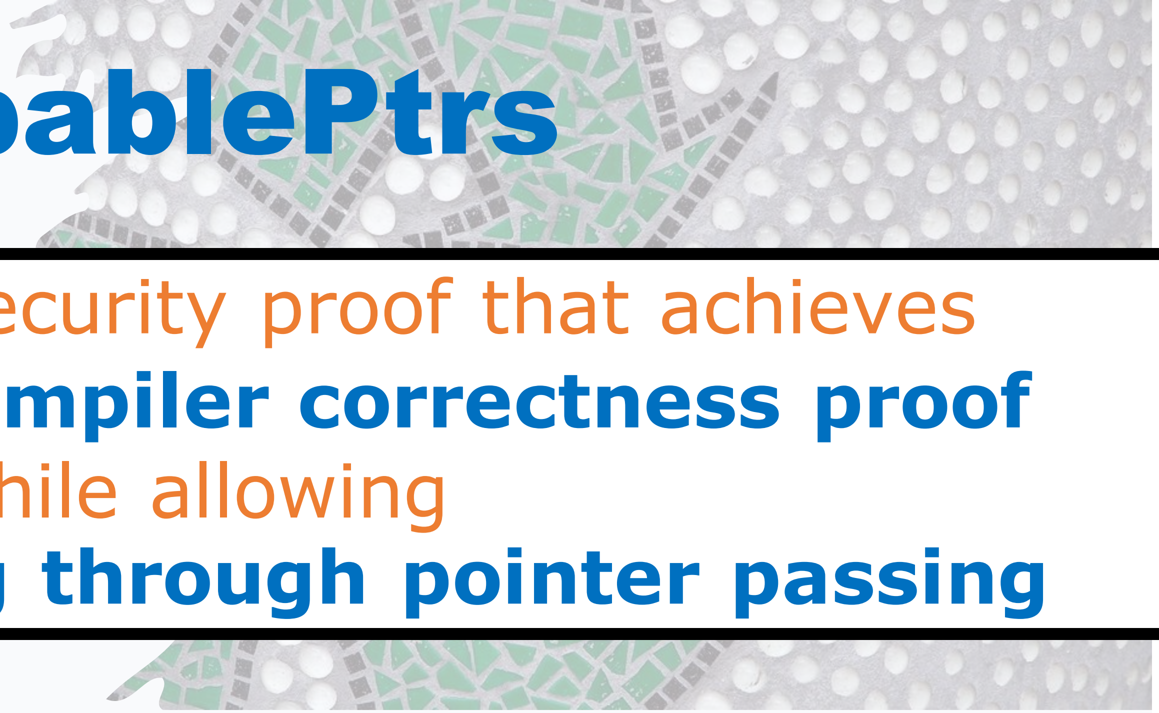

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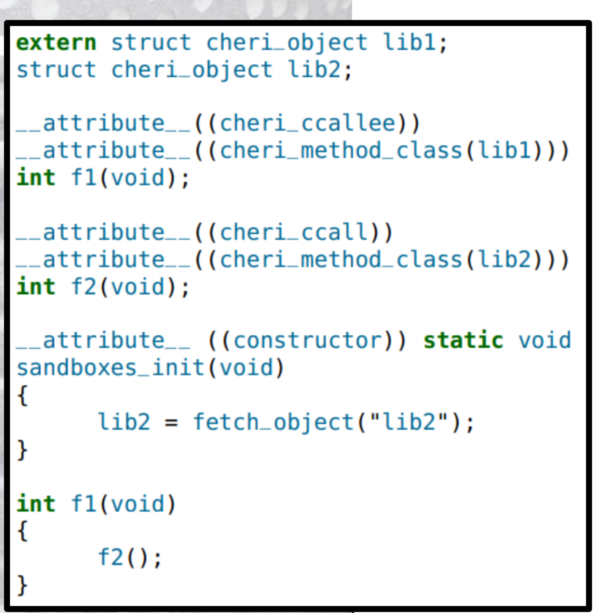
C-to-C source transform that adds CHERI annotations automatically



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extern struct cheri_object lib1;
struct cheri_object lib2;

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int f1(void);

__attribute__((cheri_ccall))
__attribute__((cheri_method_class(lib2)))
int f2(void);

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sandboxes_init(void)
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libpng
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GNU-barcode

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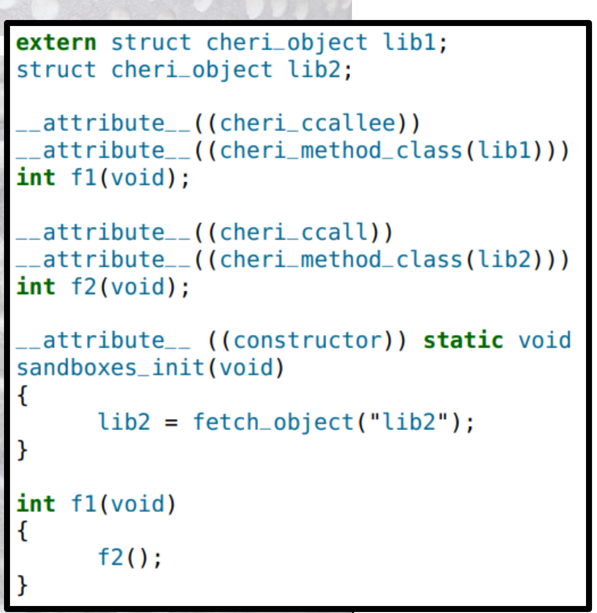

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libpng	0.15%
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GNU-barcode	3.5%

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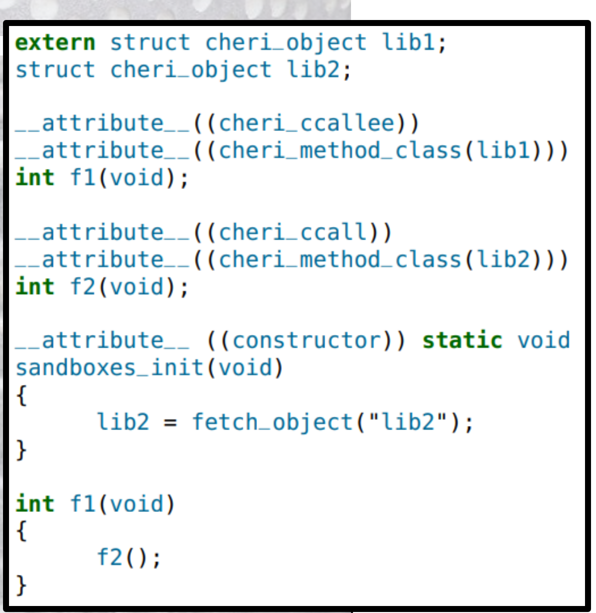

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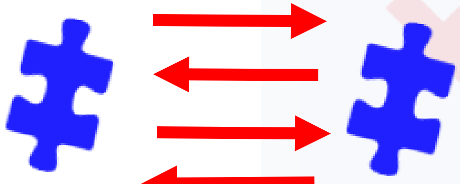

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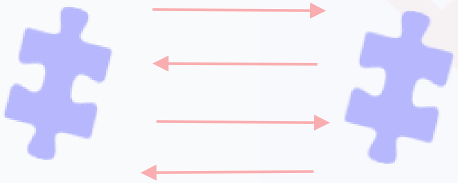

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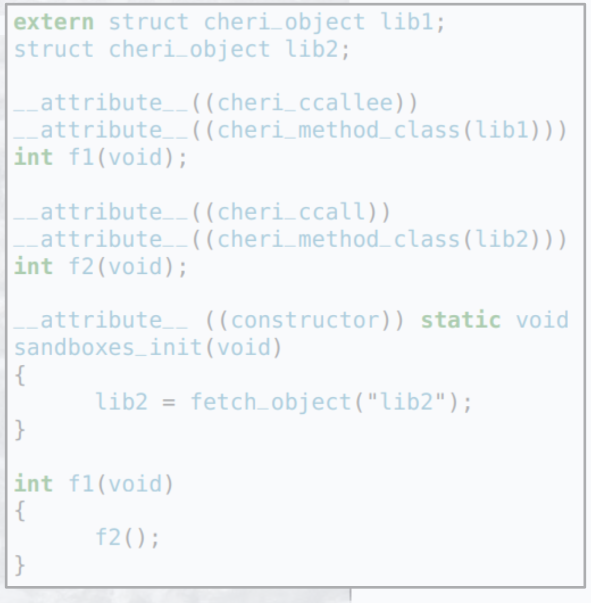

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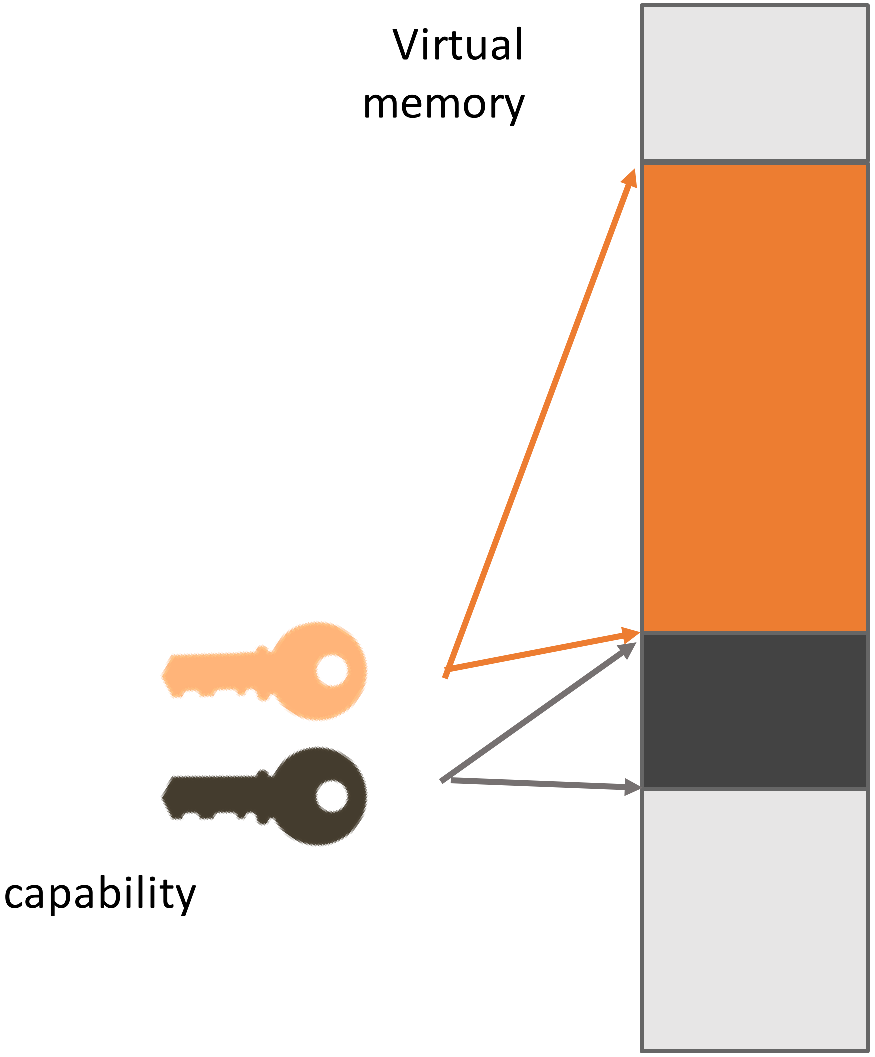
Hardware capabilities



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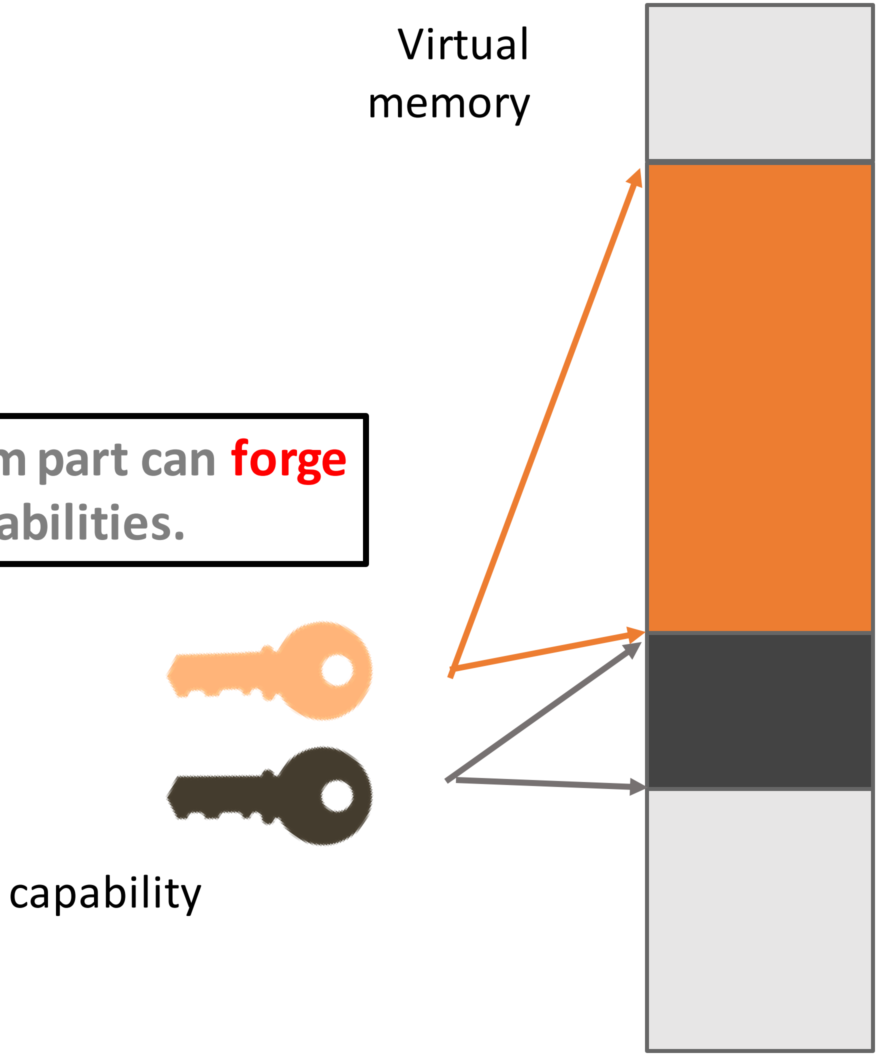

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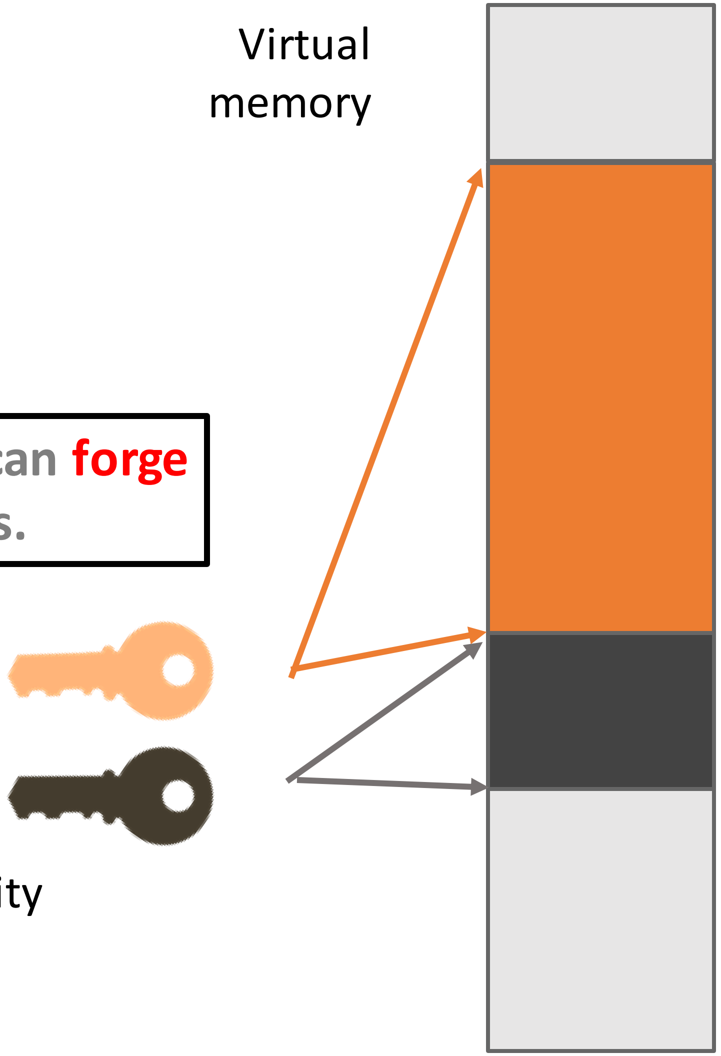

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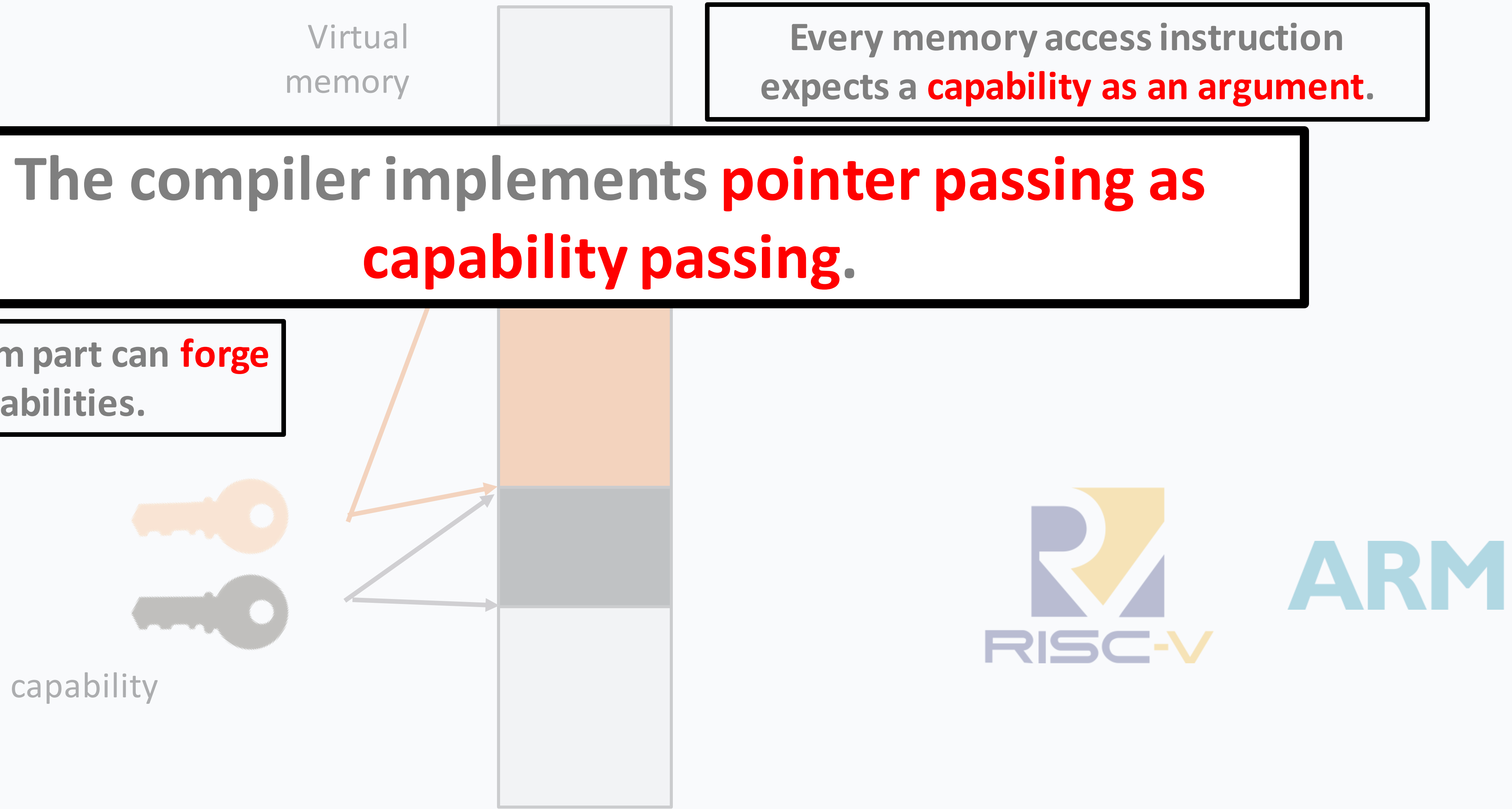

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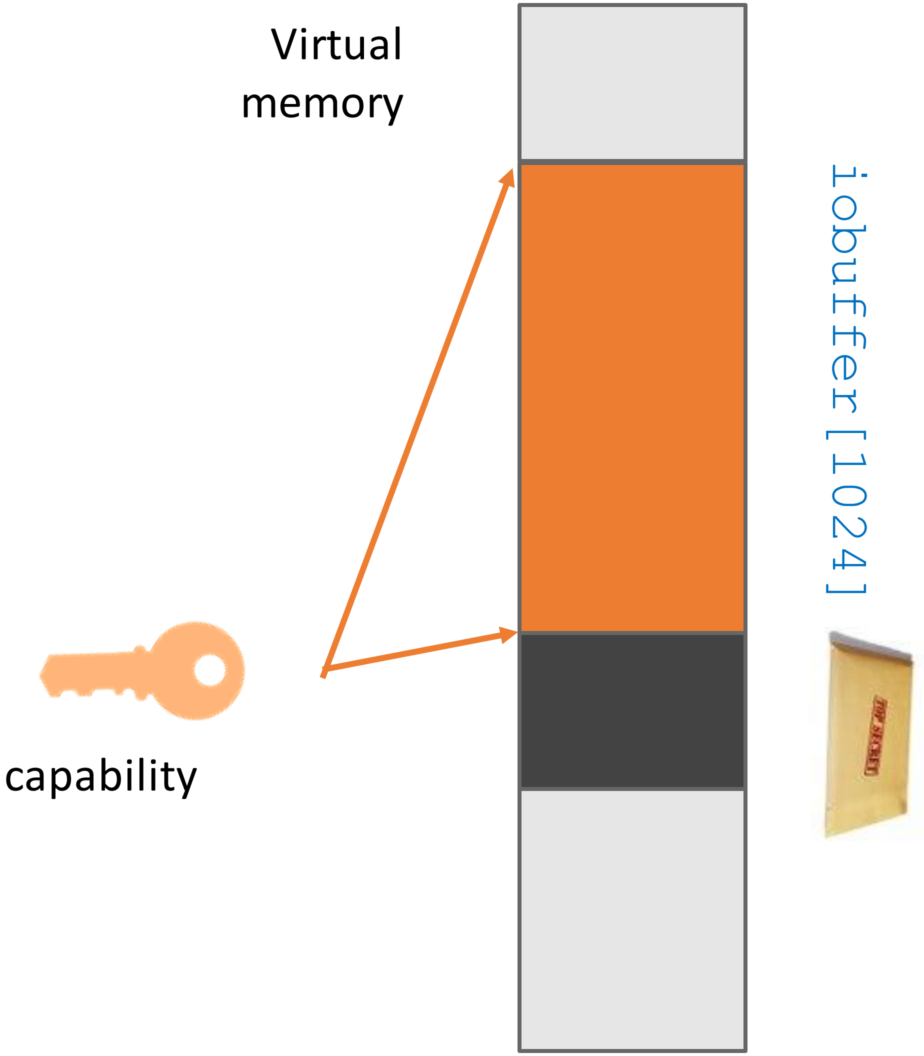

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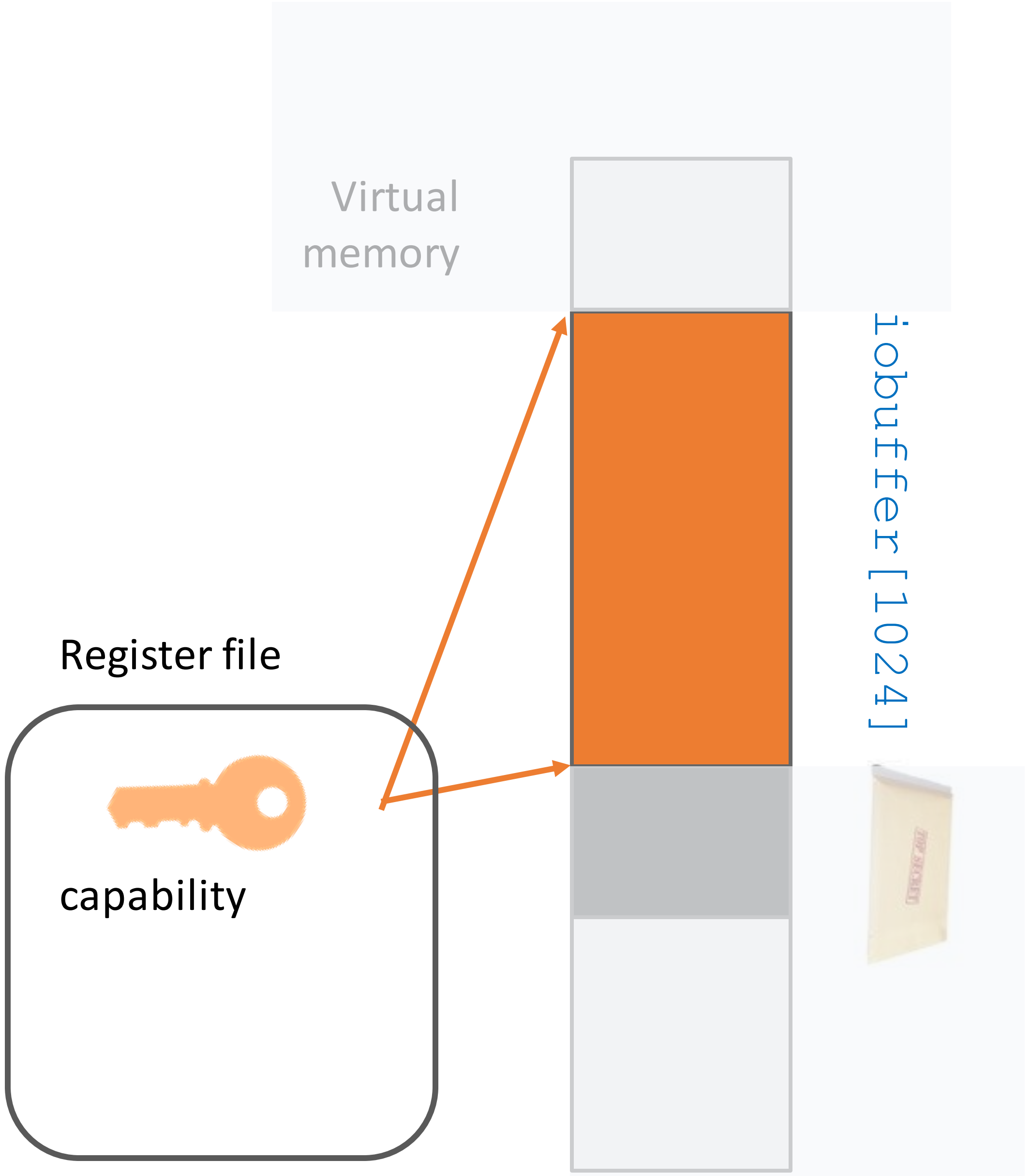

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malicious

```
char *secret_ptr =
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leak(*secret_ptr);
```

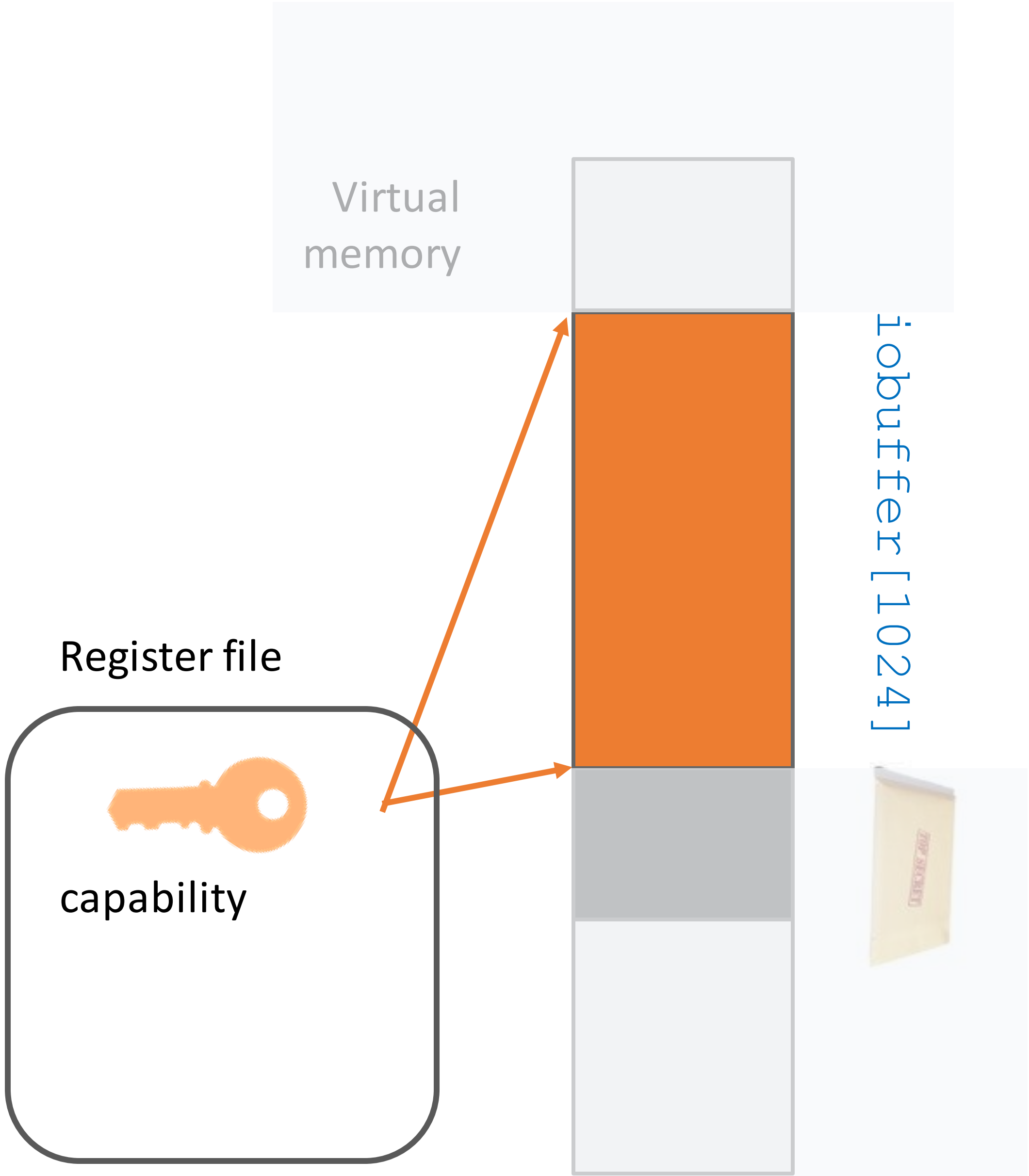

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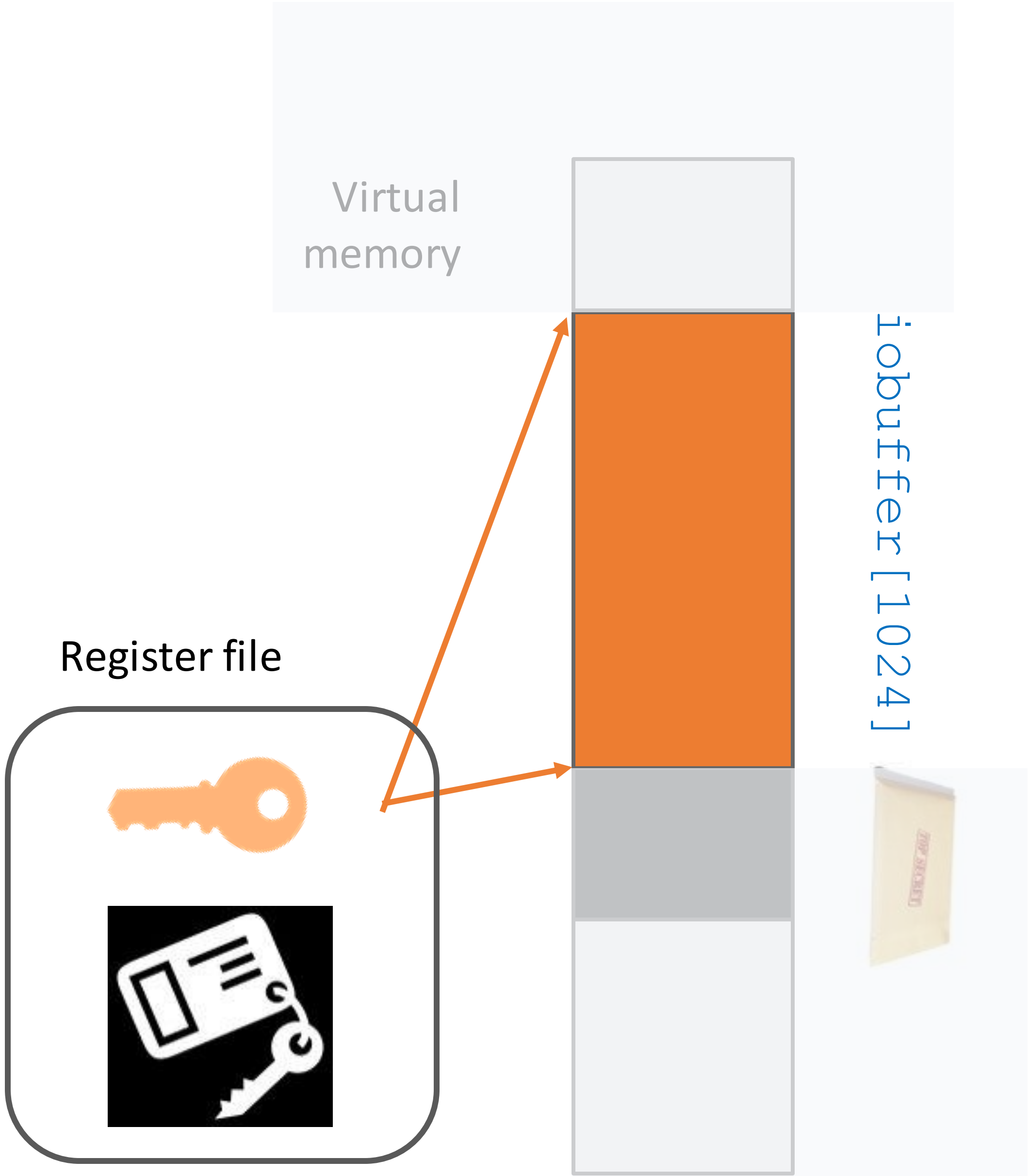

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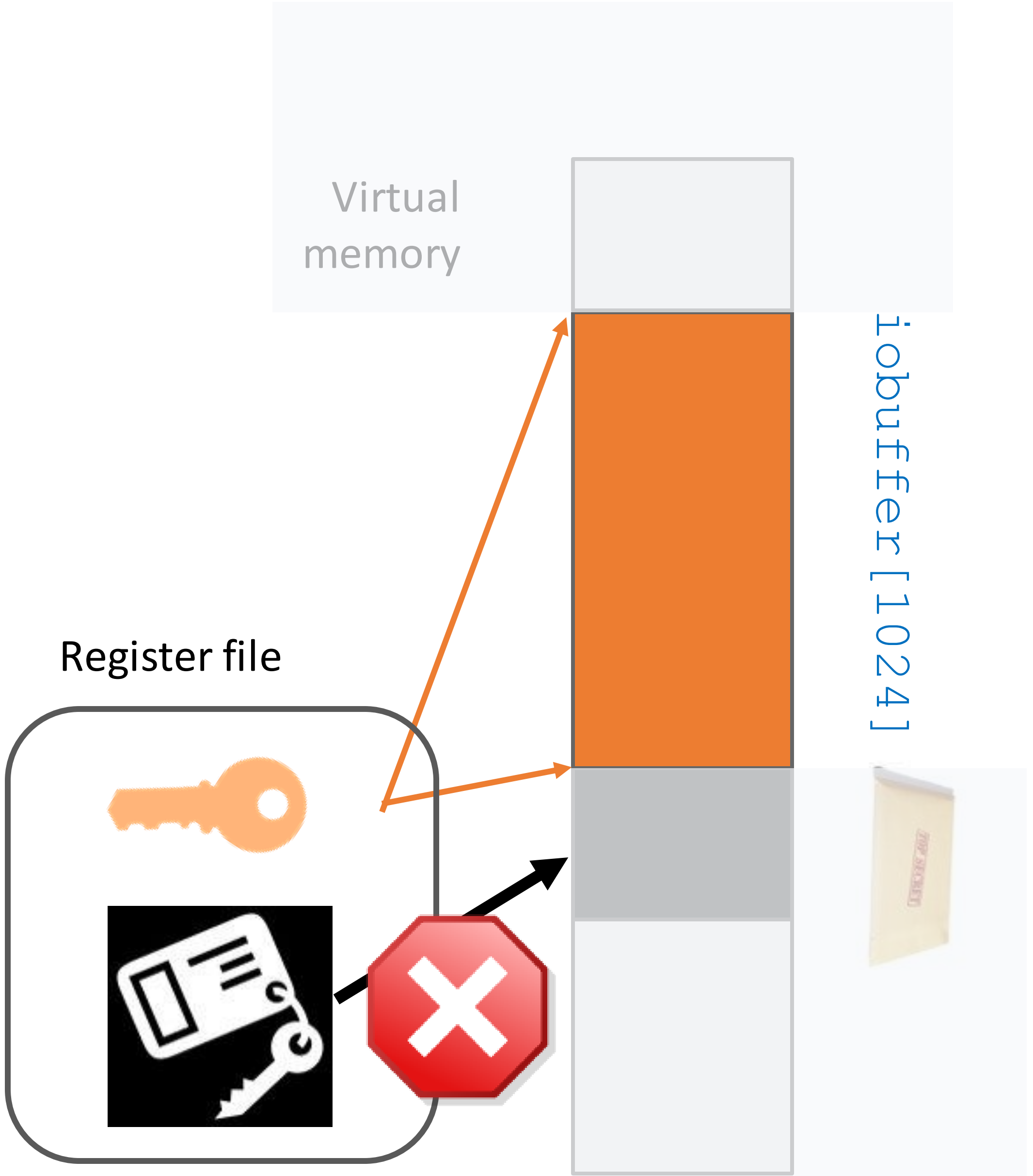

Hardwa

could be

malicious

```
char *secret_p
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```
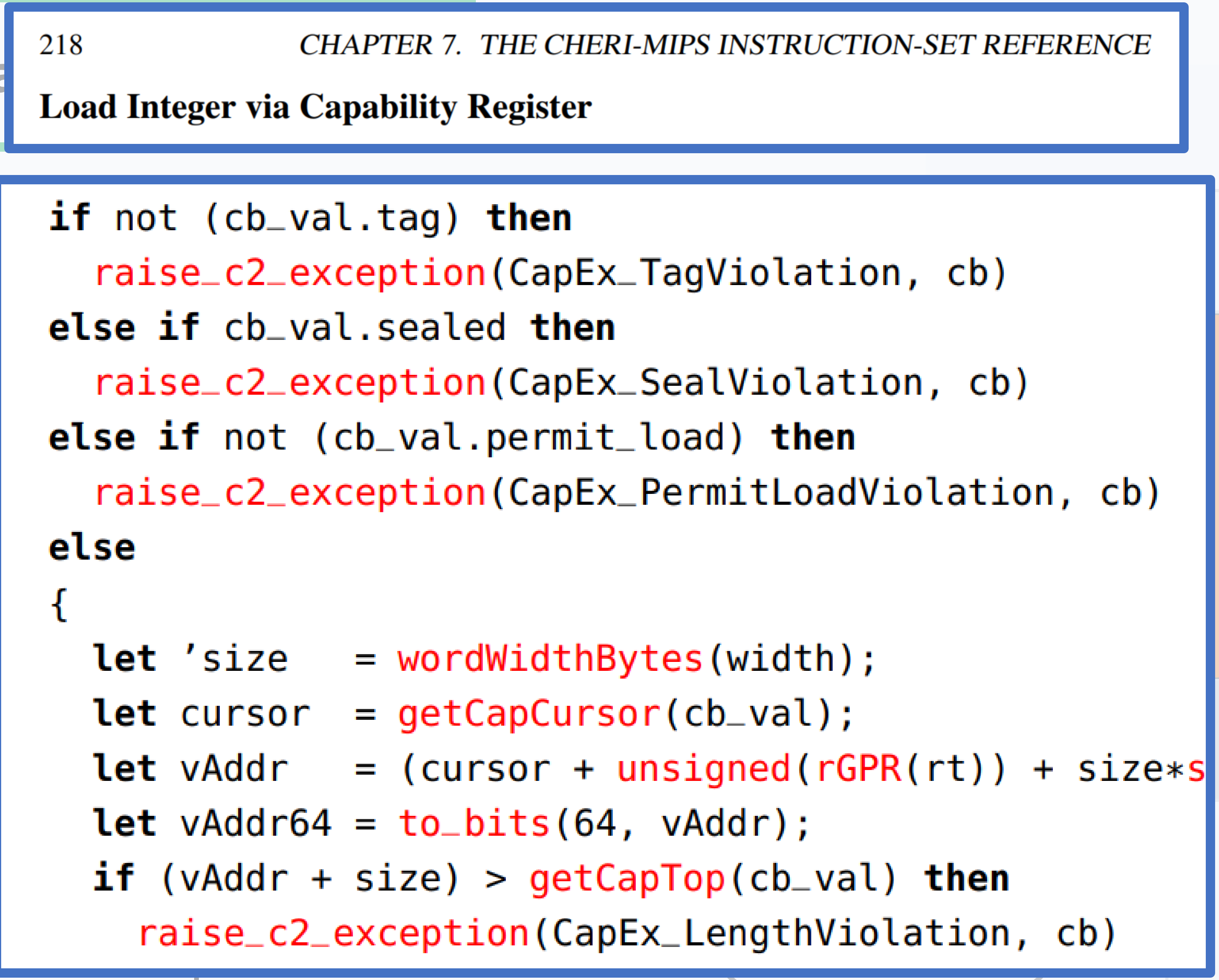

```
leak(*secret_p
```

iobuffer[1024]

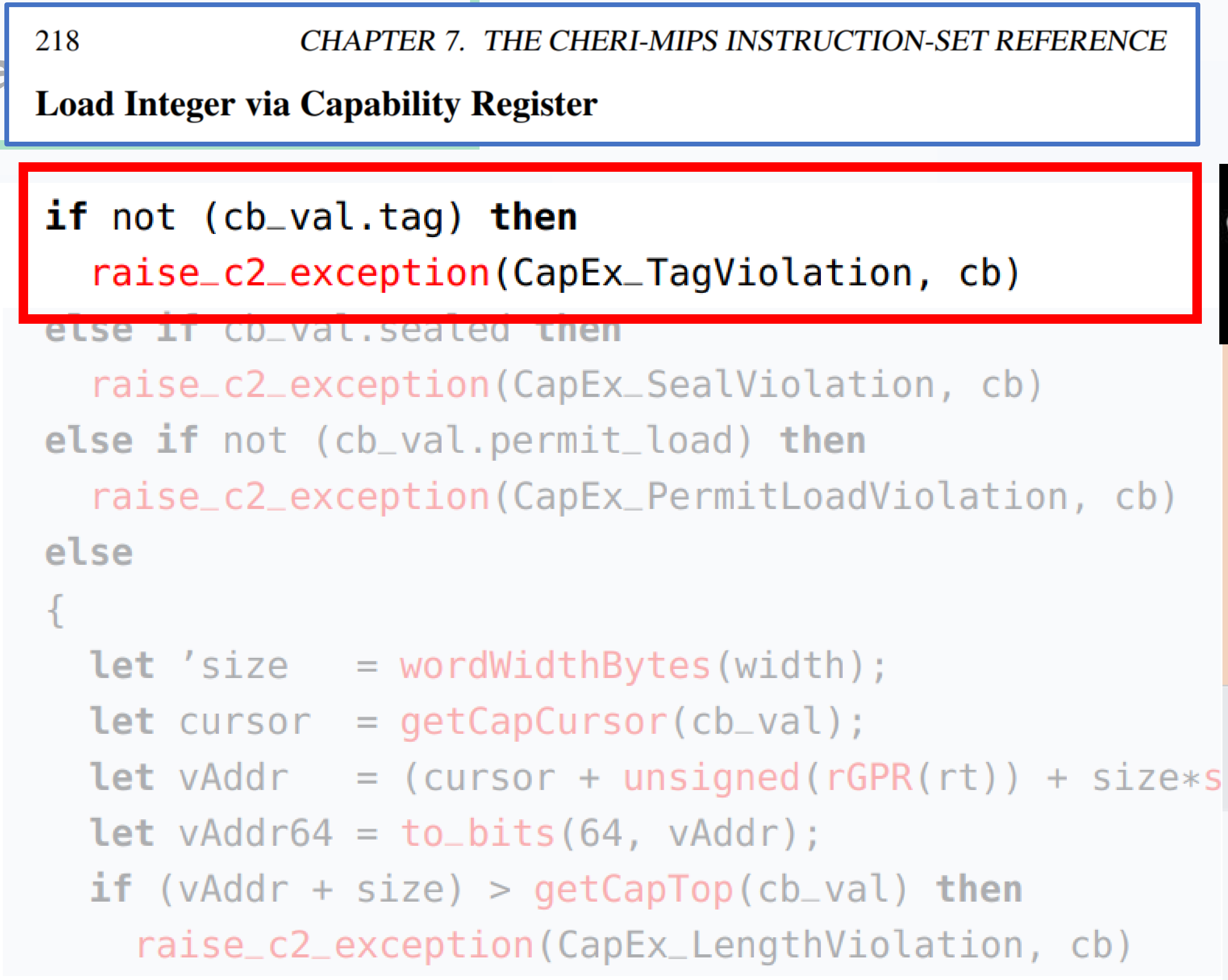


218 CHAPTER 7. THE CHERI-MIPS INSTRUCTION-SET REFERENCE

Load Integer via Capability Register

```
if not (cb_val.tag) then
  raise_c2_exception(CapEx_TagViolation, cb)
else if cb_val.sealed then
  raise_c2_exception(CapEx_SealViolation, cb)
else if not (cb_val.permit_load) then
  raise_c2_exception(CapEx_PermitLoadViolation, cb)
else
{
  let 'size   = wordWidthBytes(width);
  let cursor  = getCapCursor(cb_val);
  let vAddr   = (cursor + unsigned(rGPR(rt)) + size*s
  let vAddr64 = to_bits(64, vAddr);
  if (vAddr + size) > getCapTop(cb_val) then
    raise_c2_exception(CapEx_LengthViolation, cb)
```

Hardwa



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iobuffer[1024]

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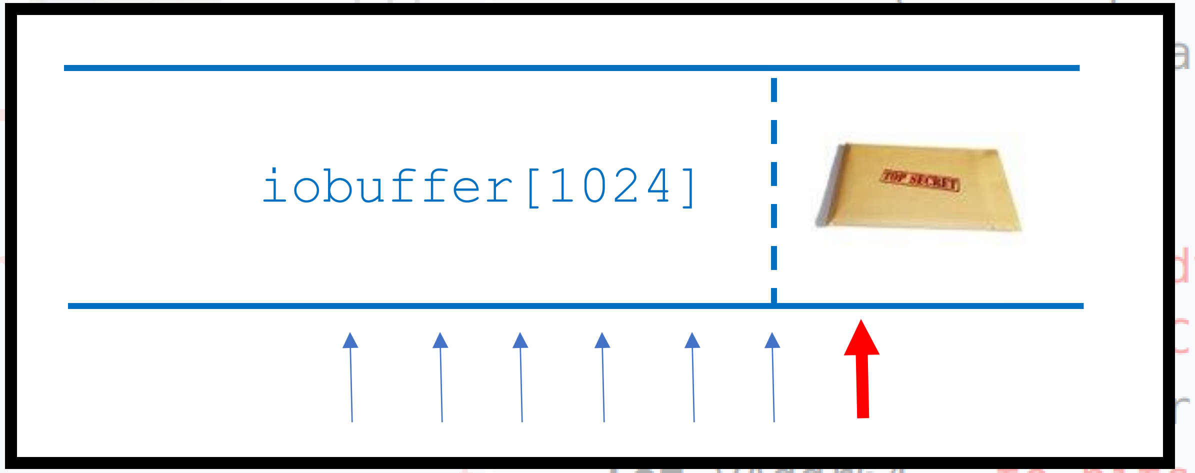

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iobuffer[1024]

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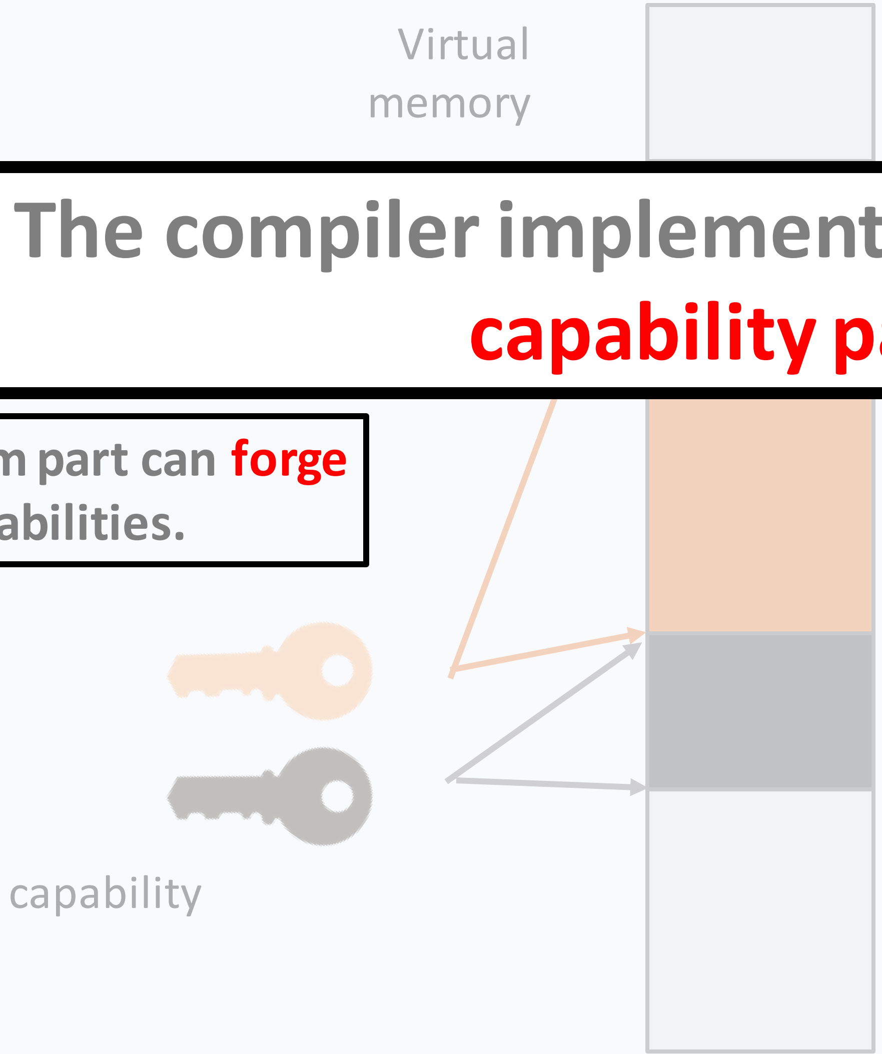

We have **two requirements** for **compiler security**

Isolate the memory of the different parts of the pr
performa
pointer

Hardware capabilities

Want a proof technique that allows us to
reuse a
correct

Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")

The definition of **compiler security** that we use:

Compiler Full Abstraction

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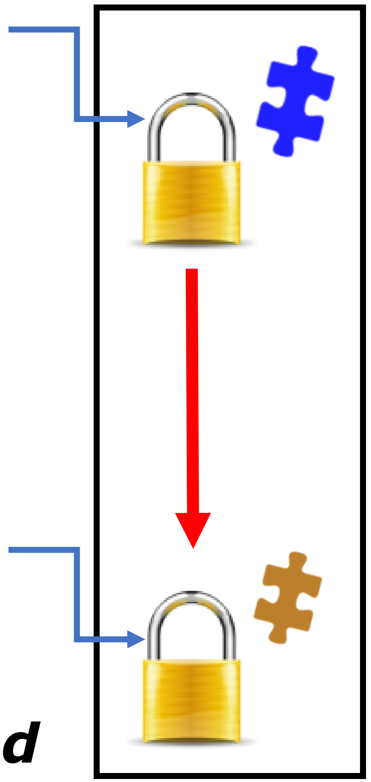


security property of the source program part

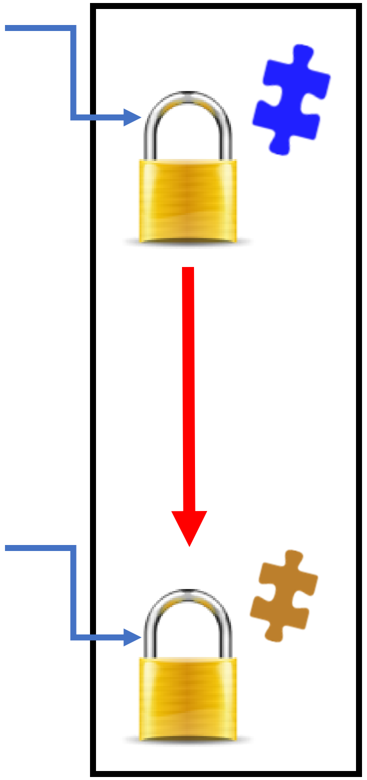
security property of the ***compiled*** program part

The definition of **compiler security** that we use:

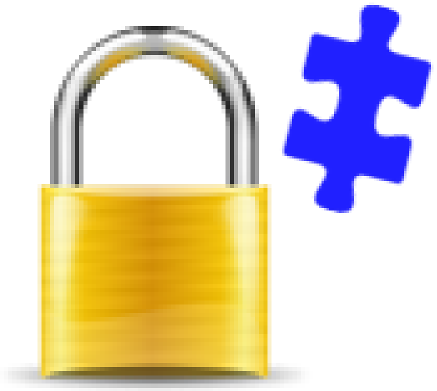
Compiler Full Abstraction

Confidentiality of the secrets of the source program part

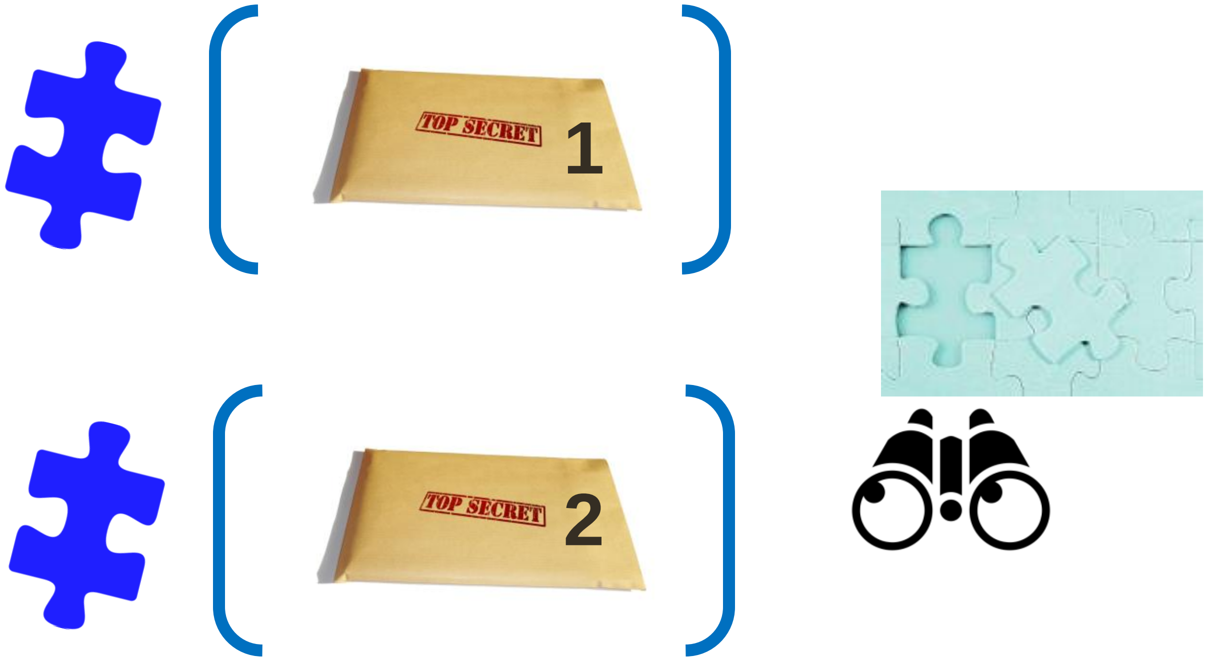
Confidentiality of the secrets of the ***compiled*** program part



A partial program is **secure**



when **NO library** can distinguish two runs (with **two different secrets**) from each other.



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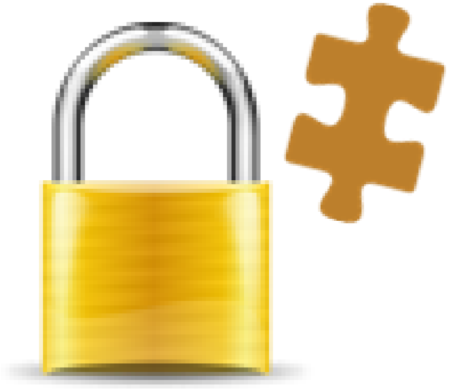

The same definition for the **target language** too

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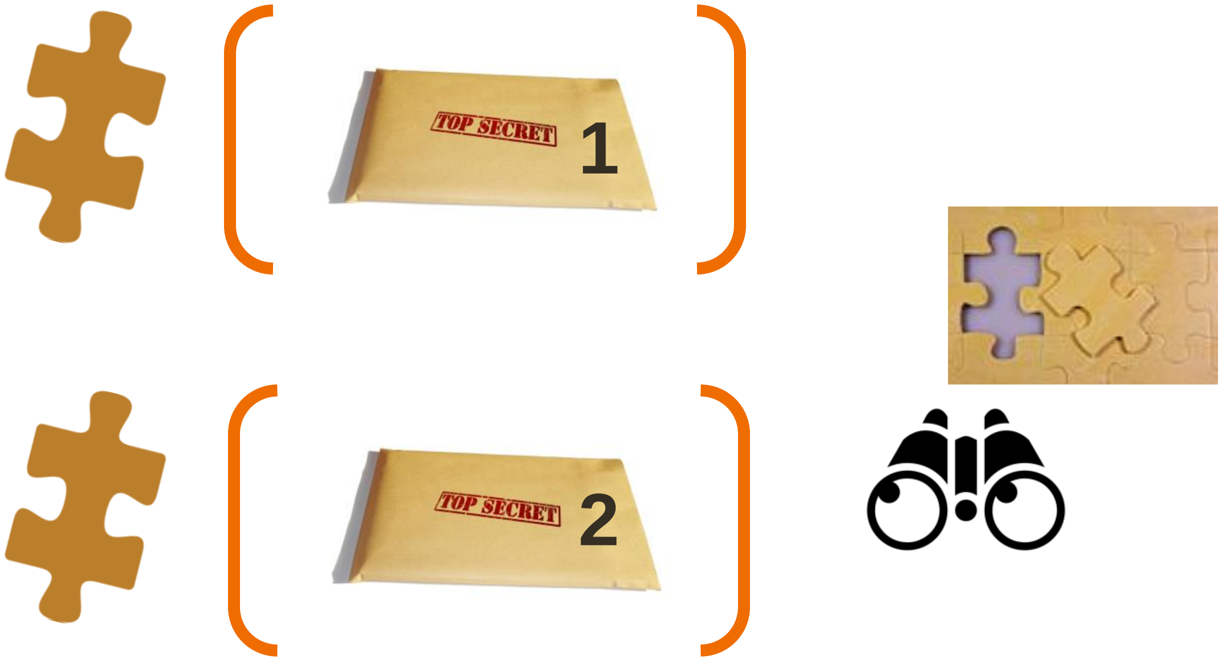

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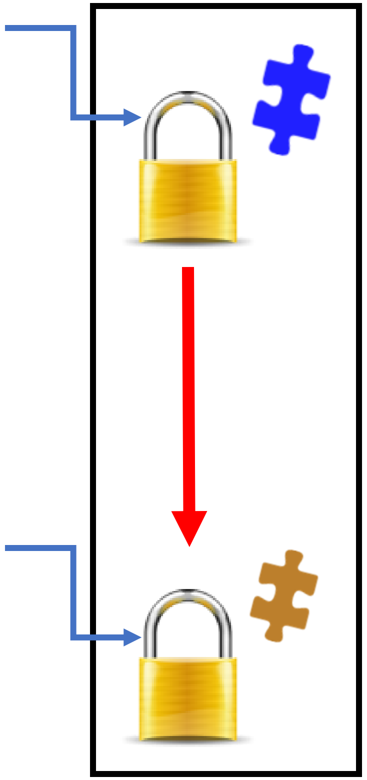

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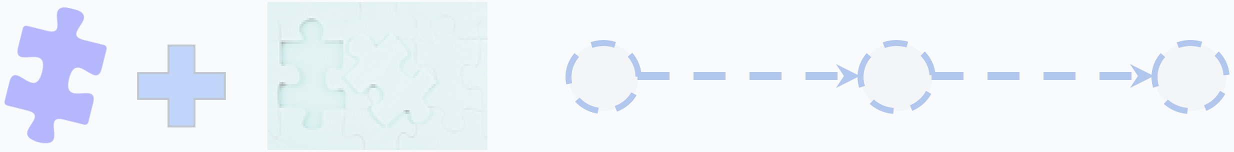
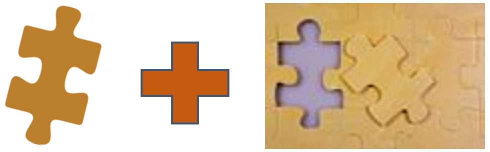
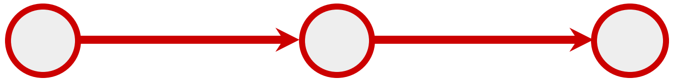


compiled program part

untrusted third-party library





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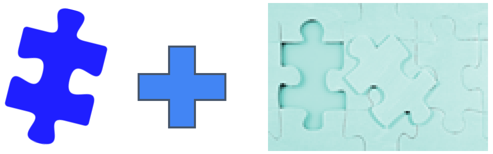
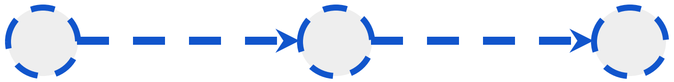
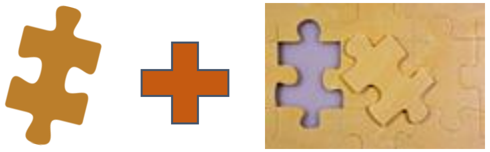
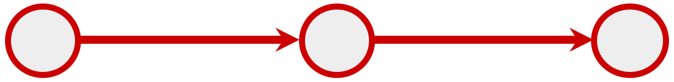




source program part ∃ mimicking source library

compiled program part **untrusted** third-party library





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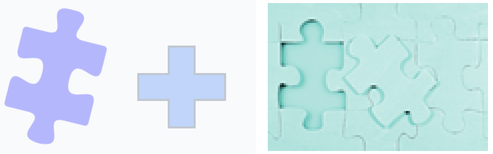


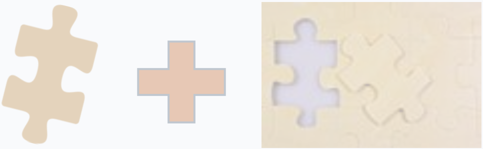
source program part

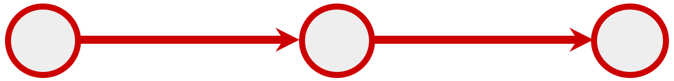
∃ mimicking source library

Trace-directed Back-translation

compiled program part

untrusted third-party library





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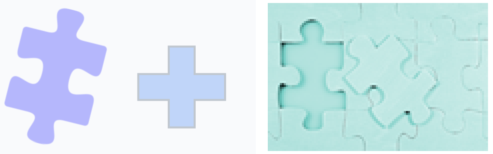

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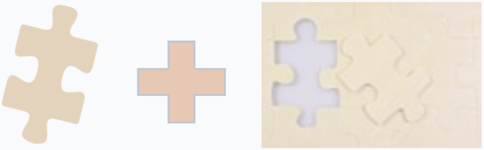

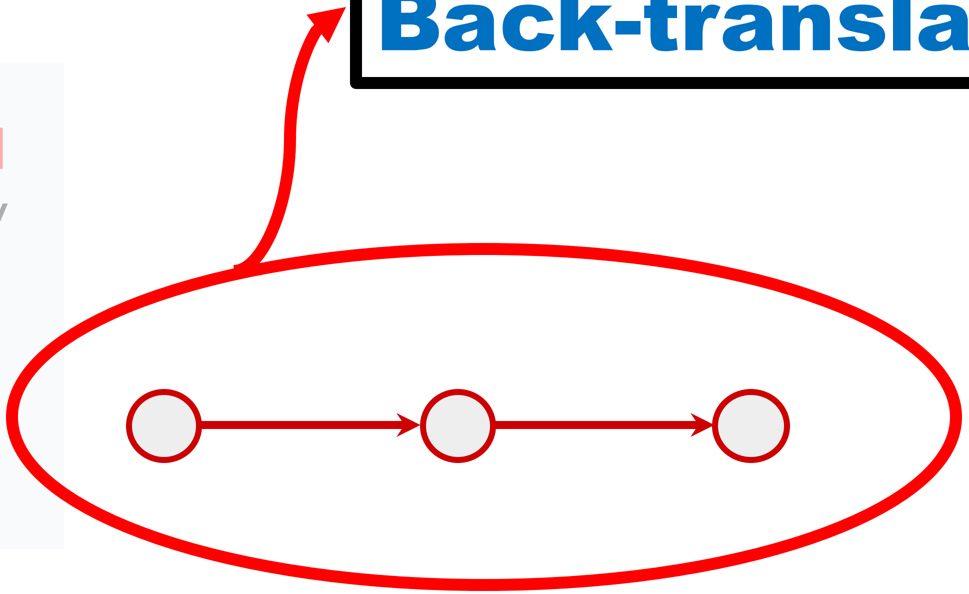

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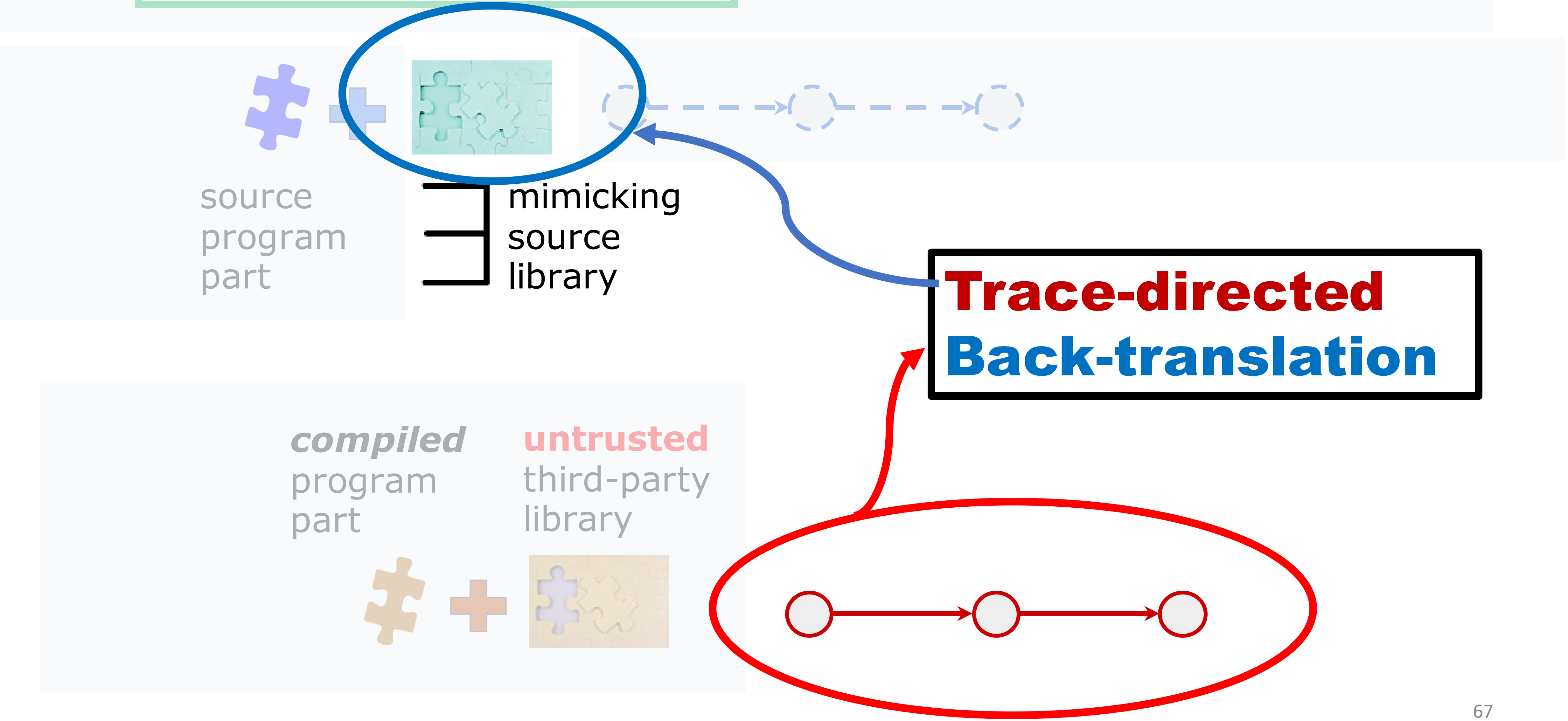

source program part

mimicking source library

Trace-directed Back-translation

compiled program part

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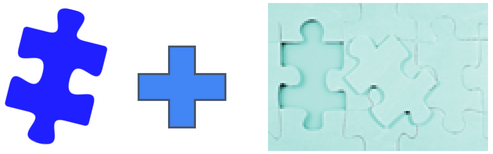

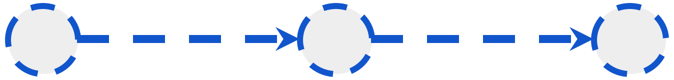

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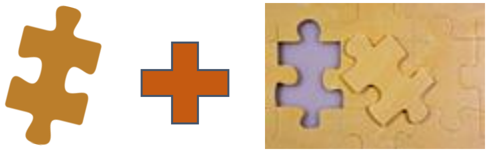

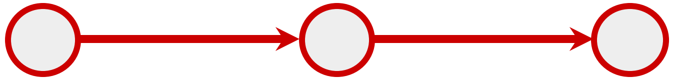

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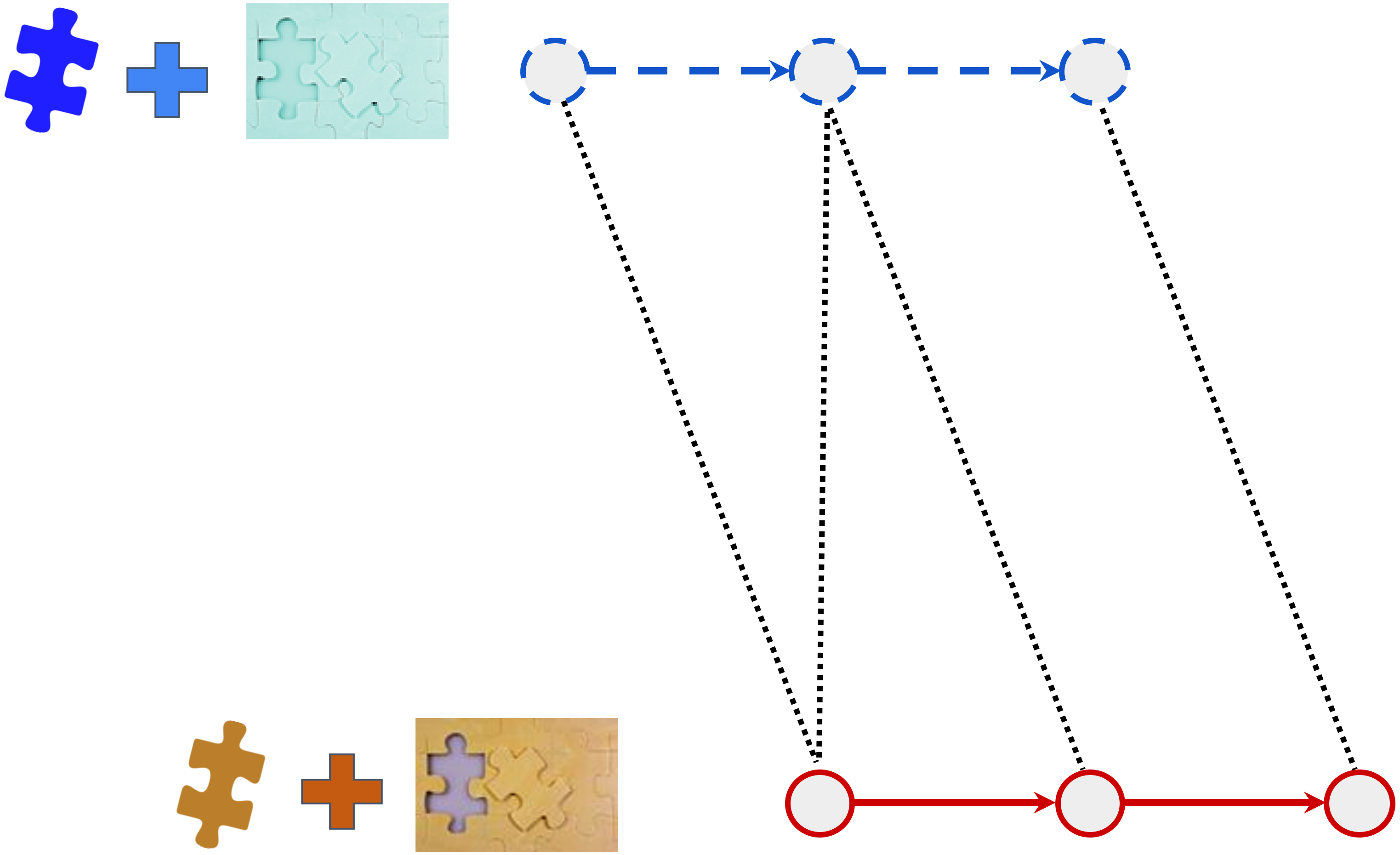

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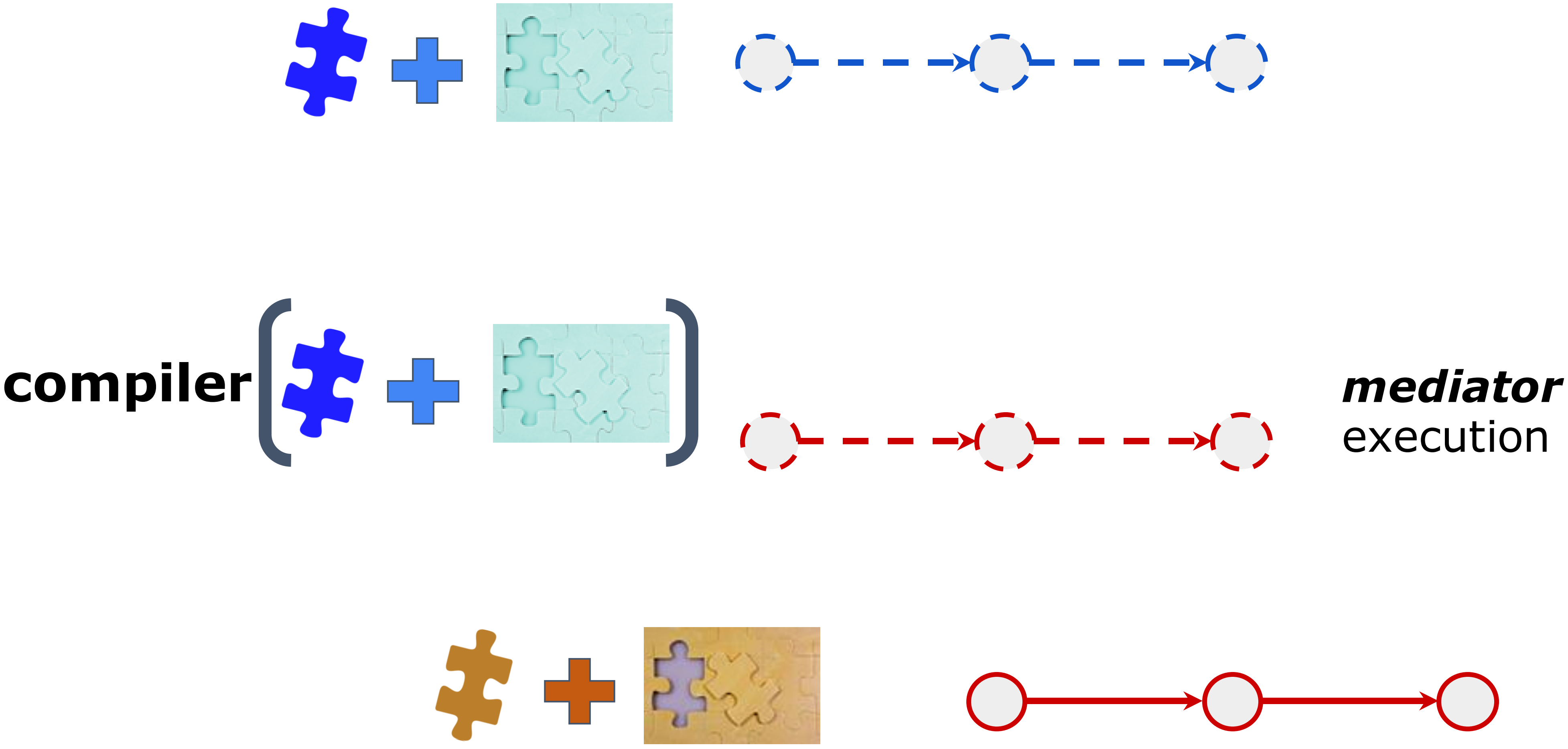
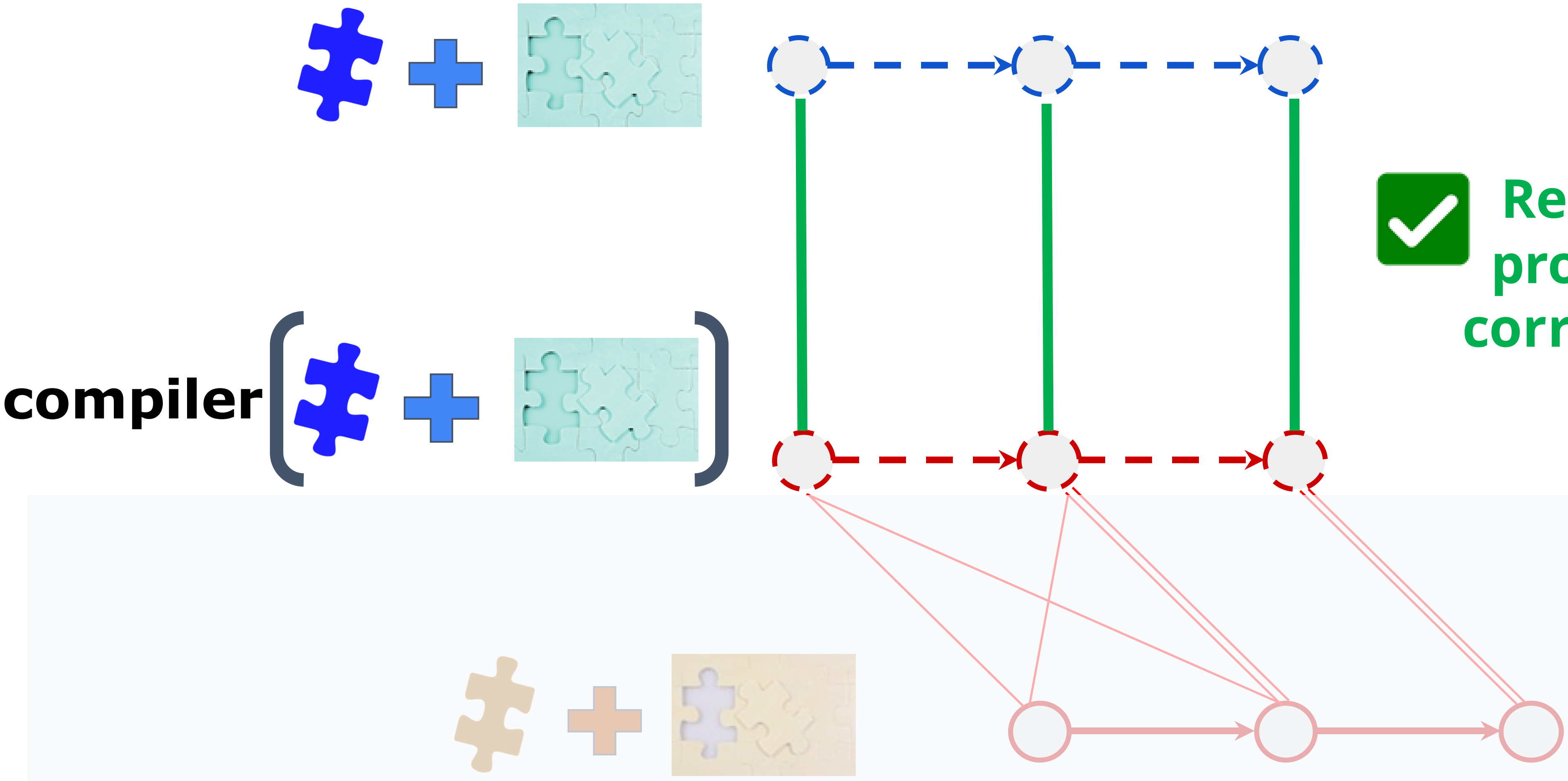


compiler

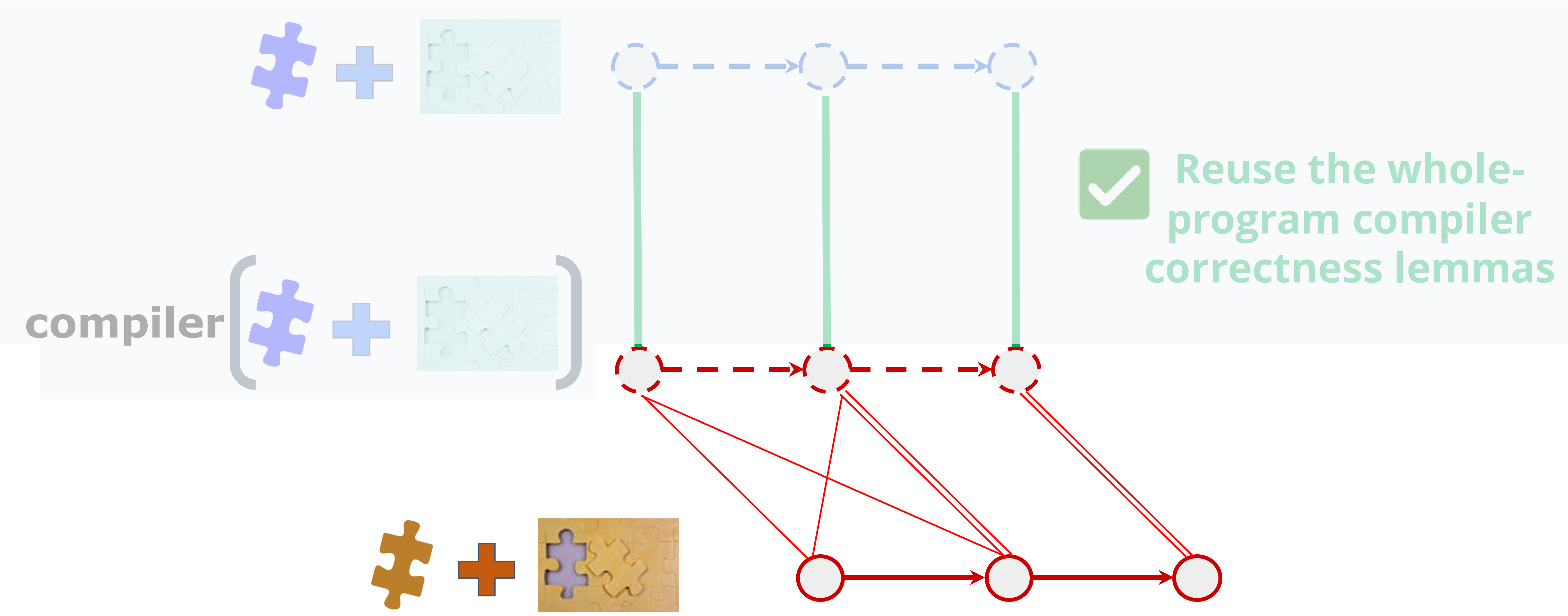
mediator
execution

Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")



✓ Reuse the whole-program compiler correctness lemmas

Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")



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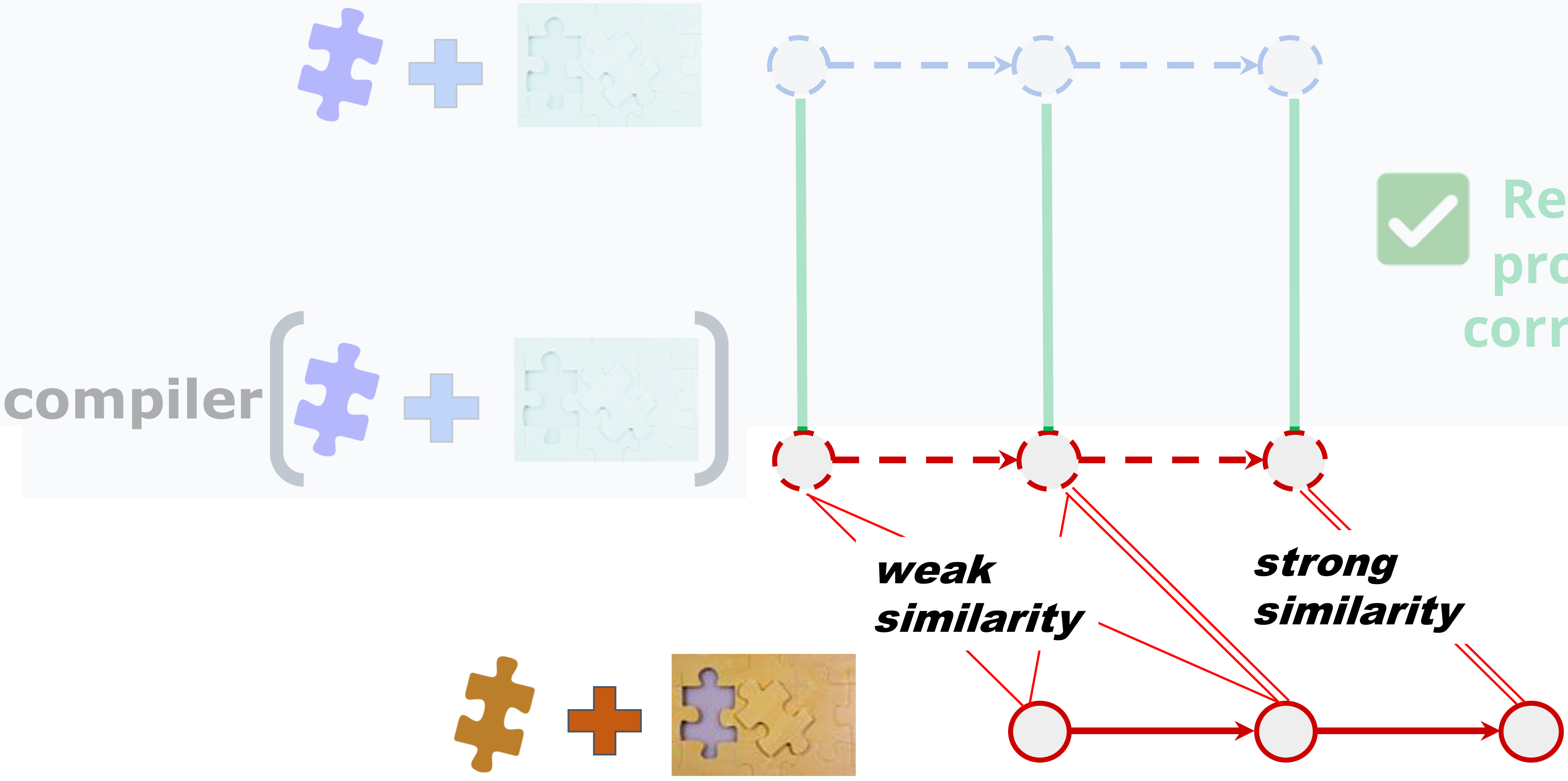

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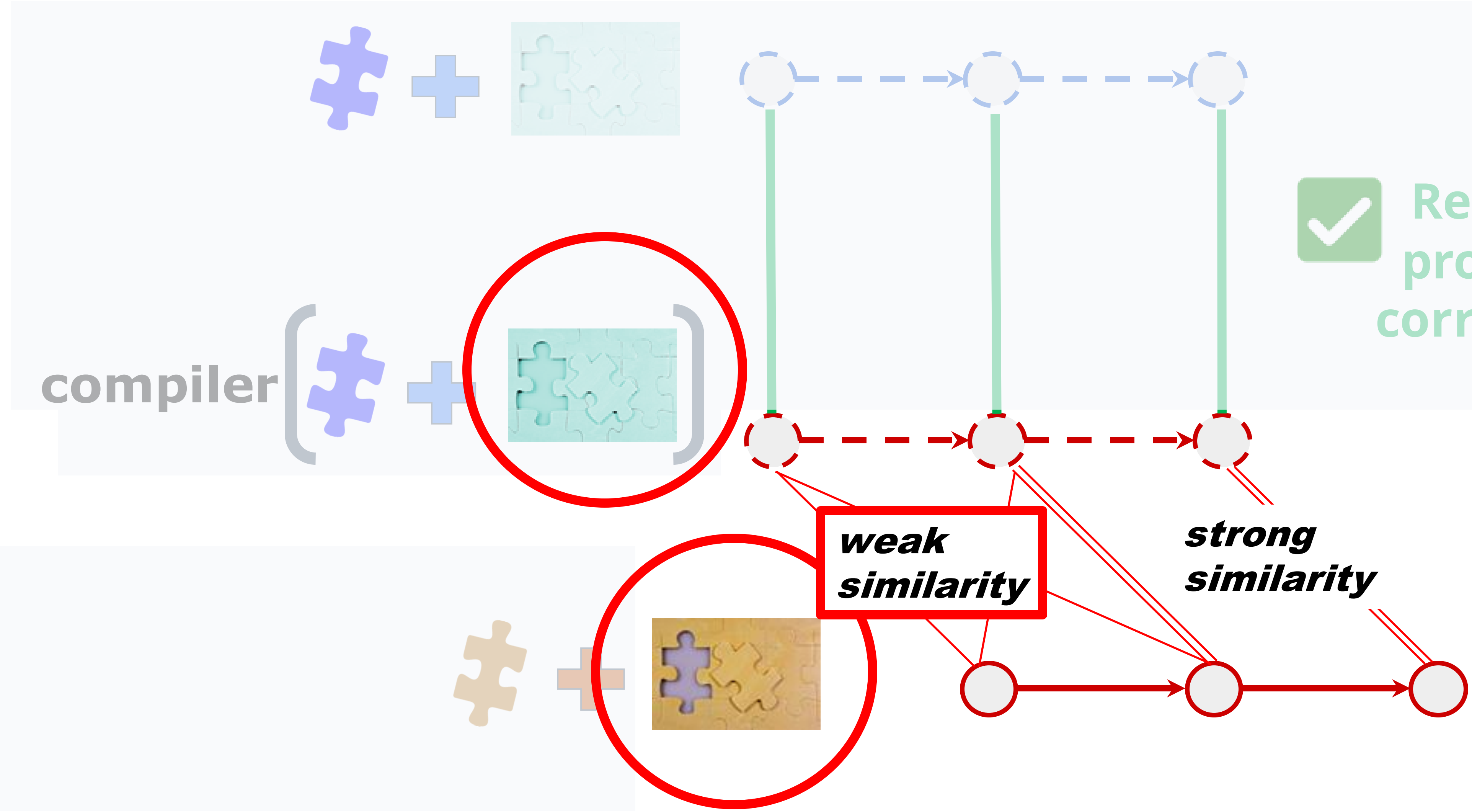

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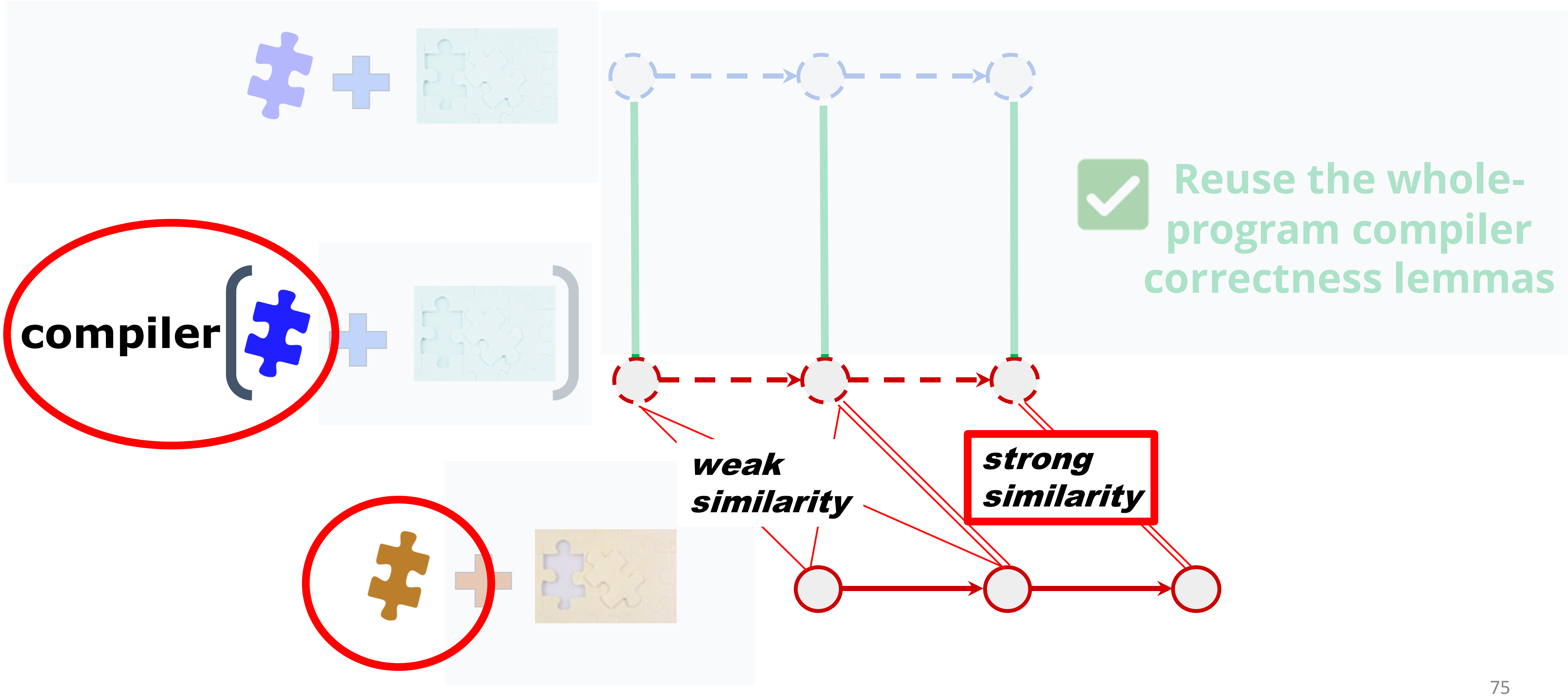

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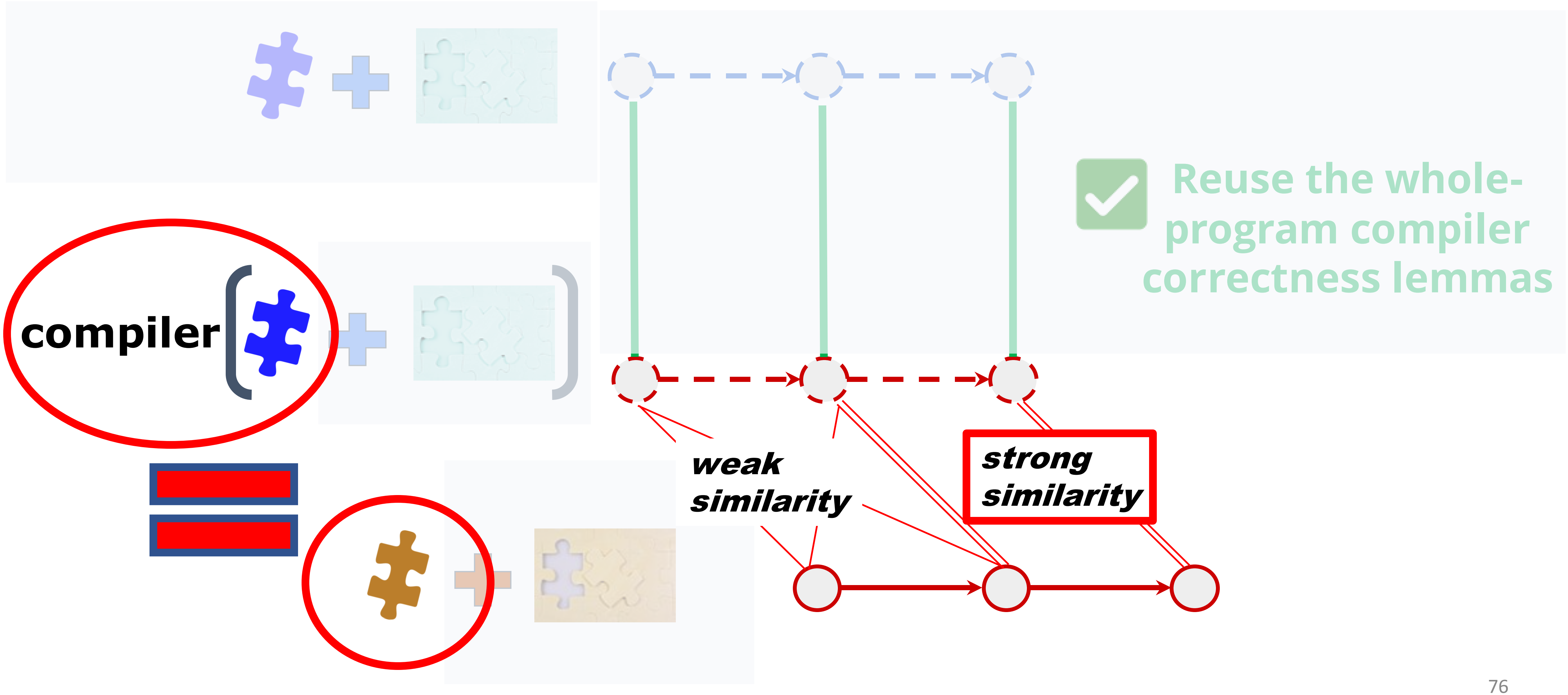
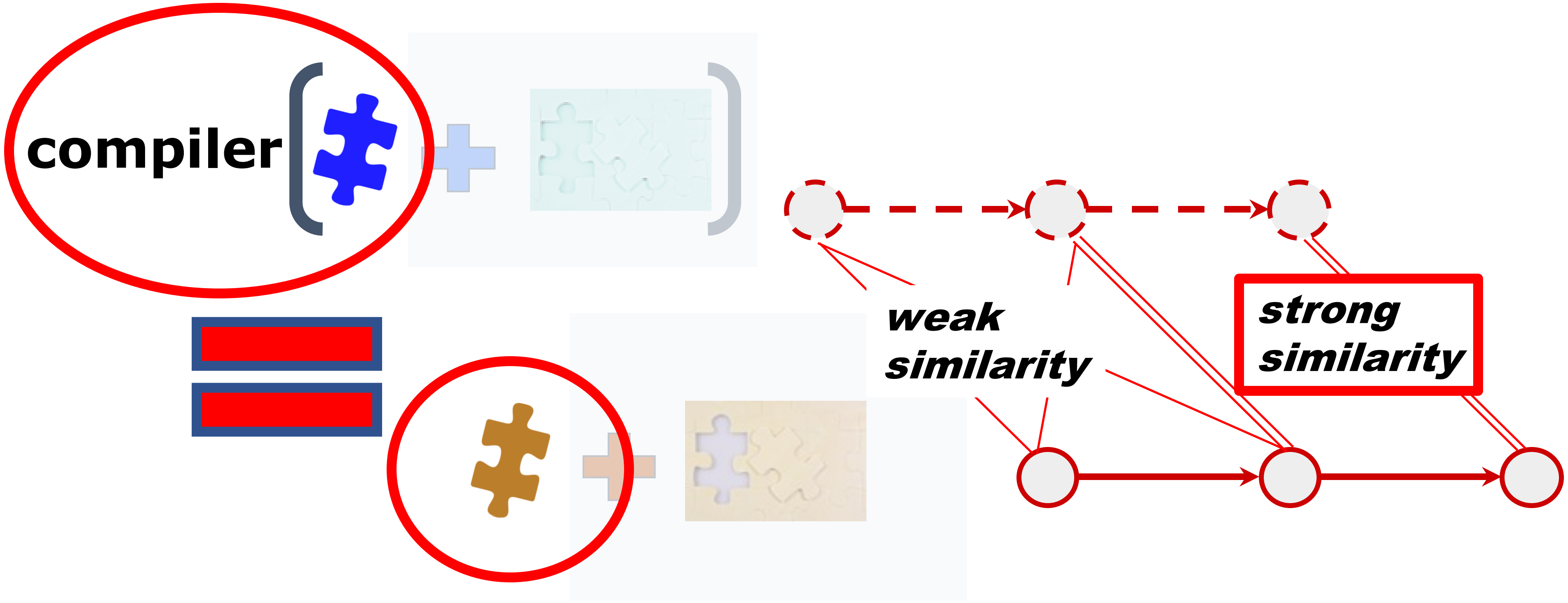
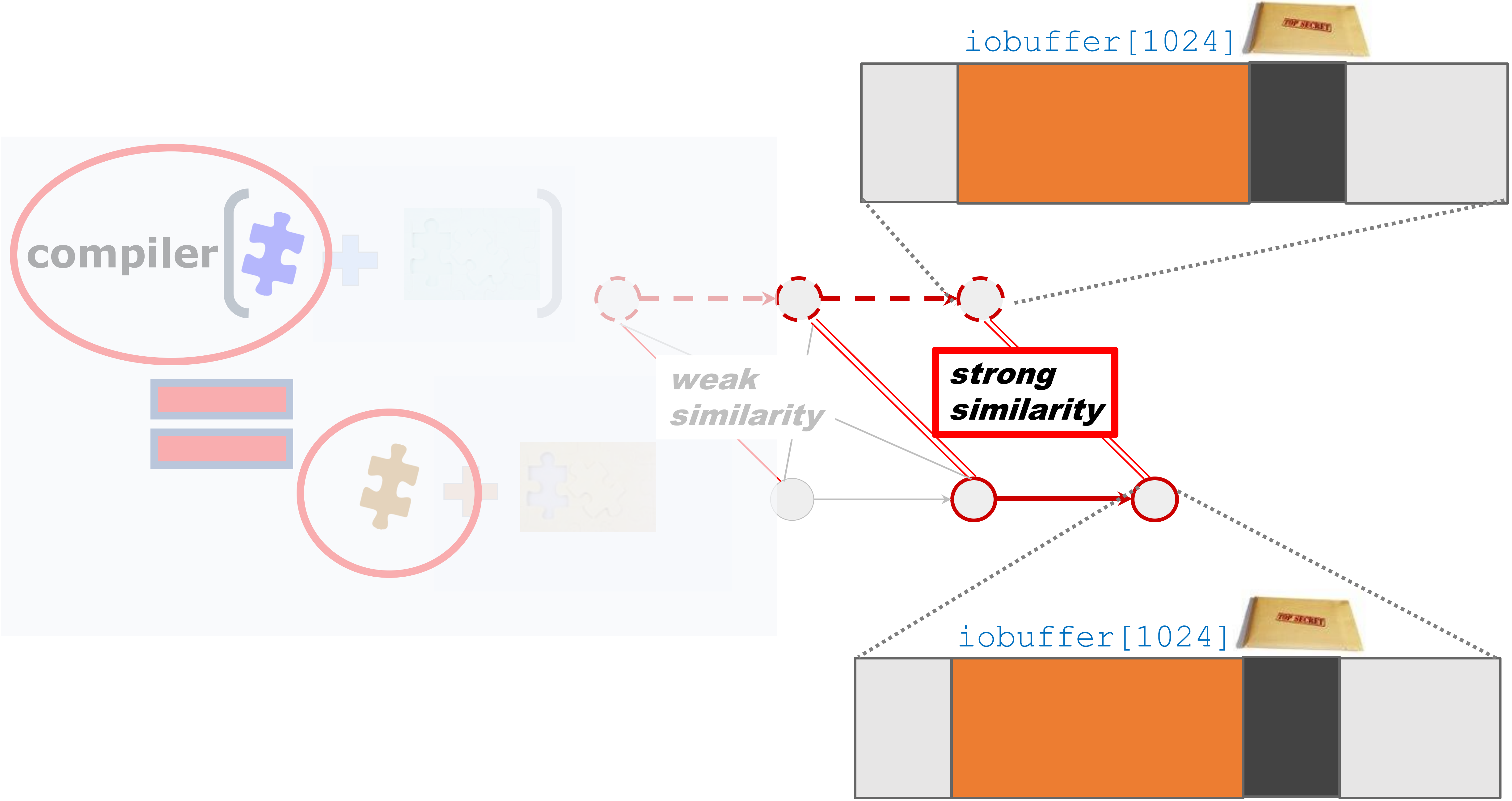




compiler

weak similarity

strong similarity


iobuffer[1024]
TOP SECRET
compiler
weak similarity
strong similarity
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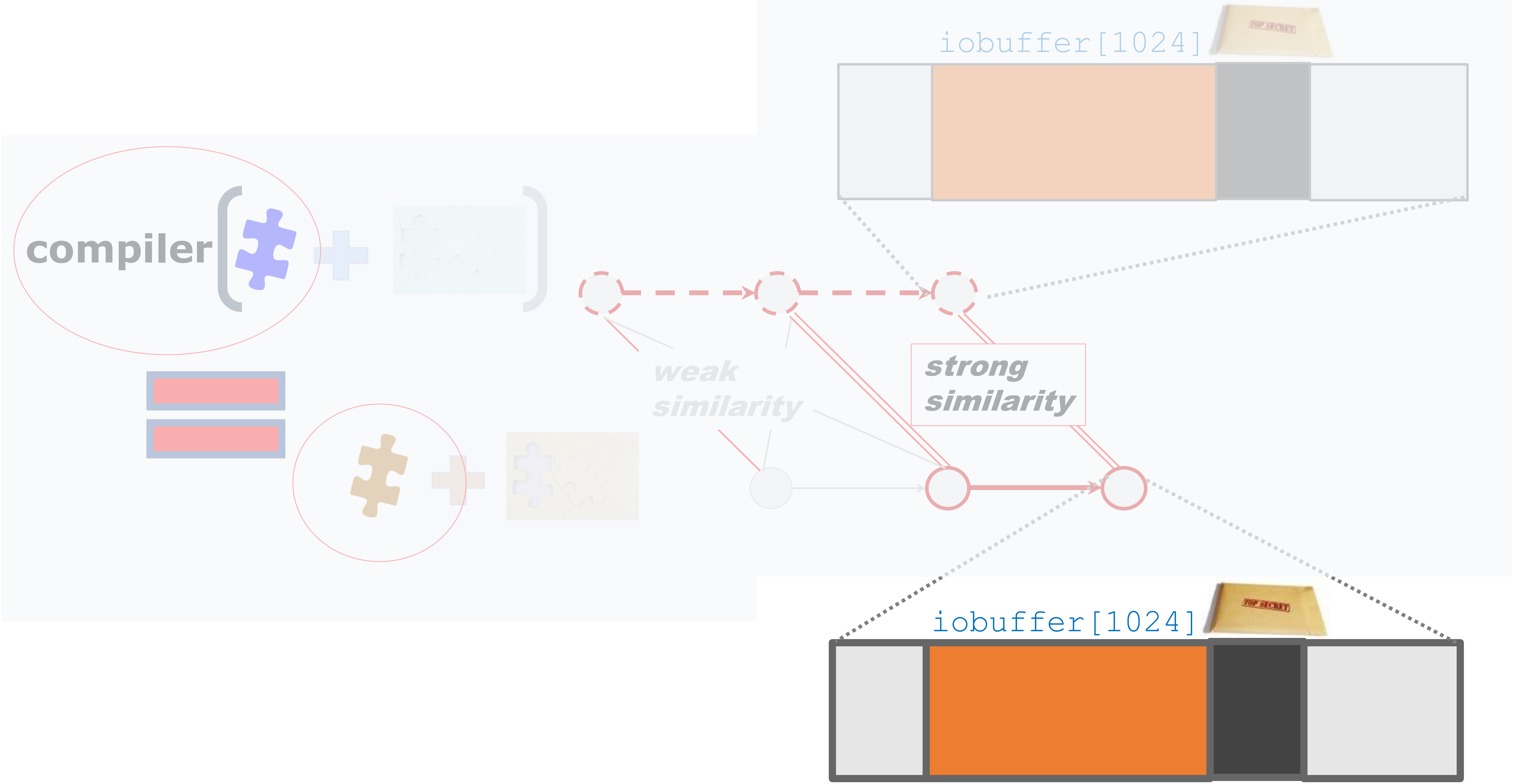
TOP SECRET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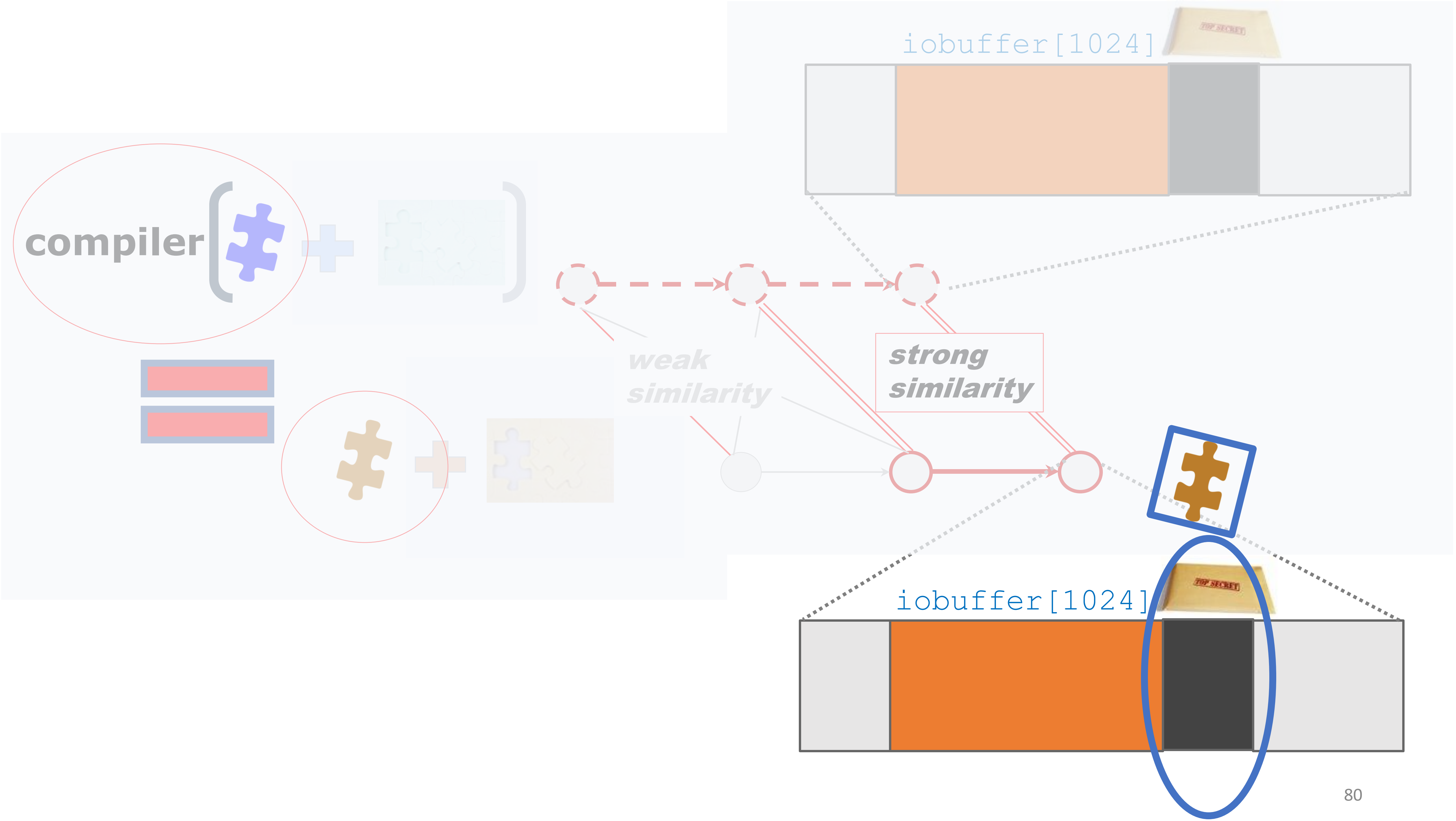
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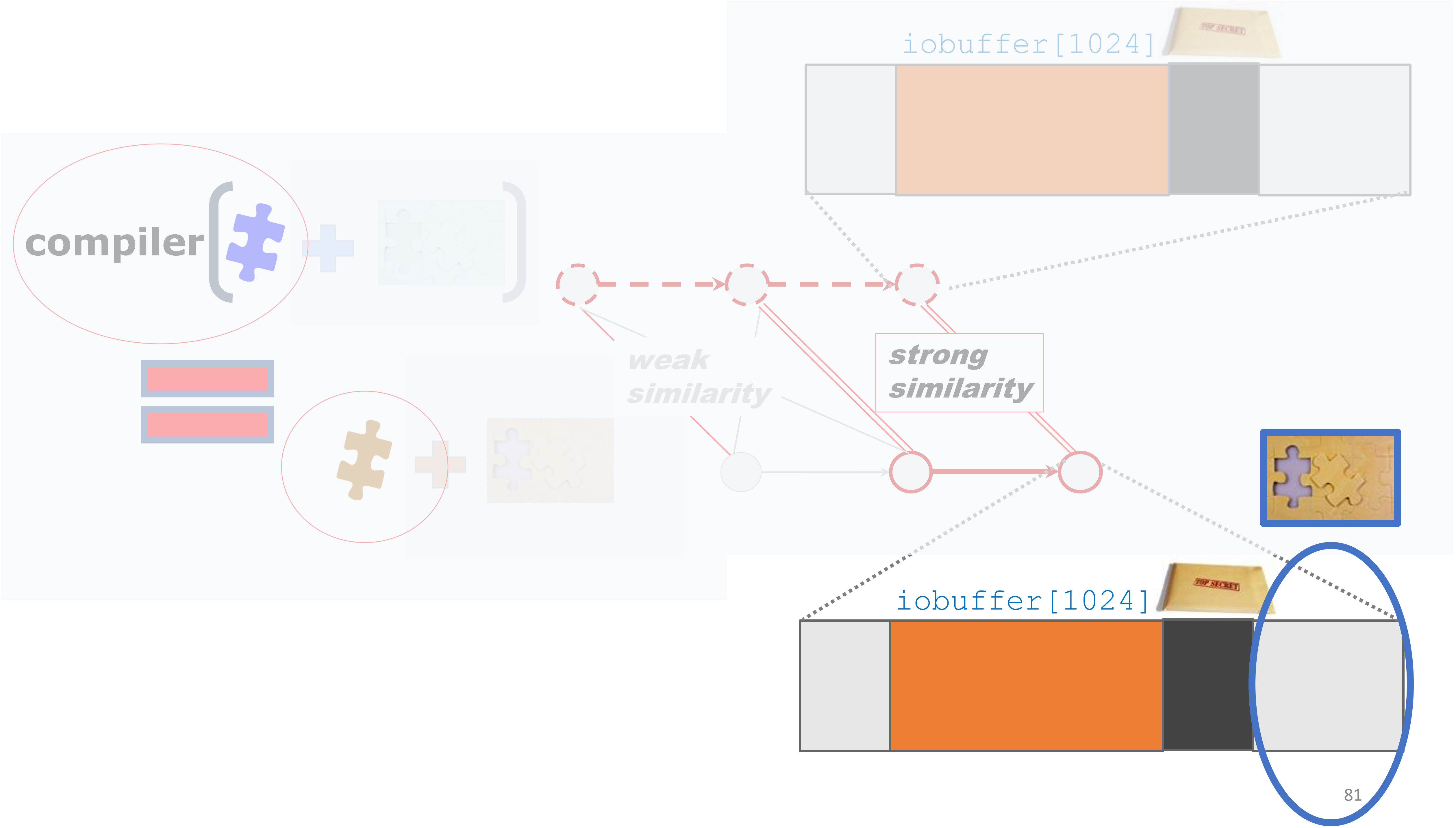

iobuffer[1024]

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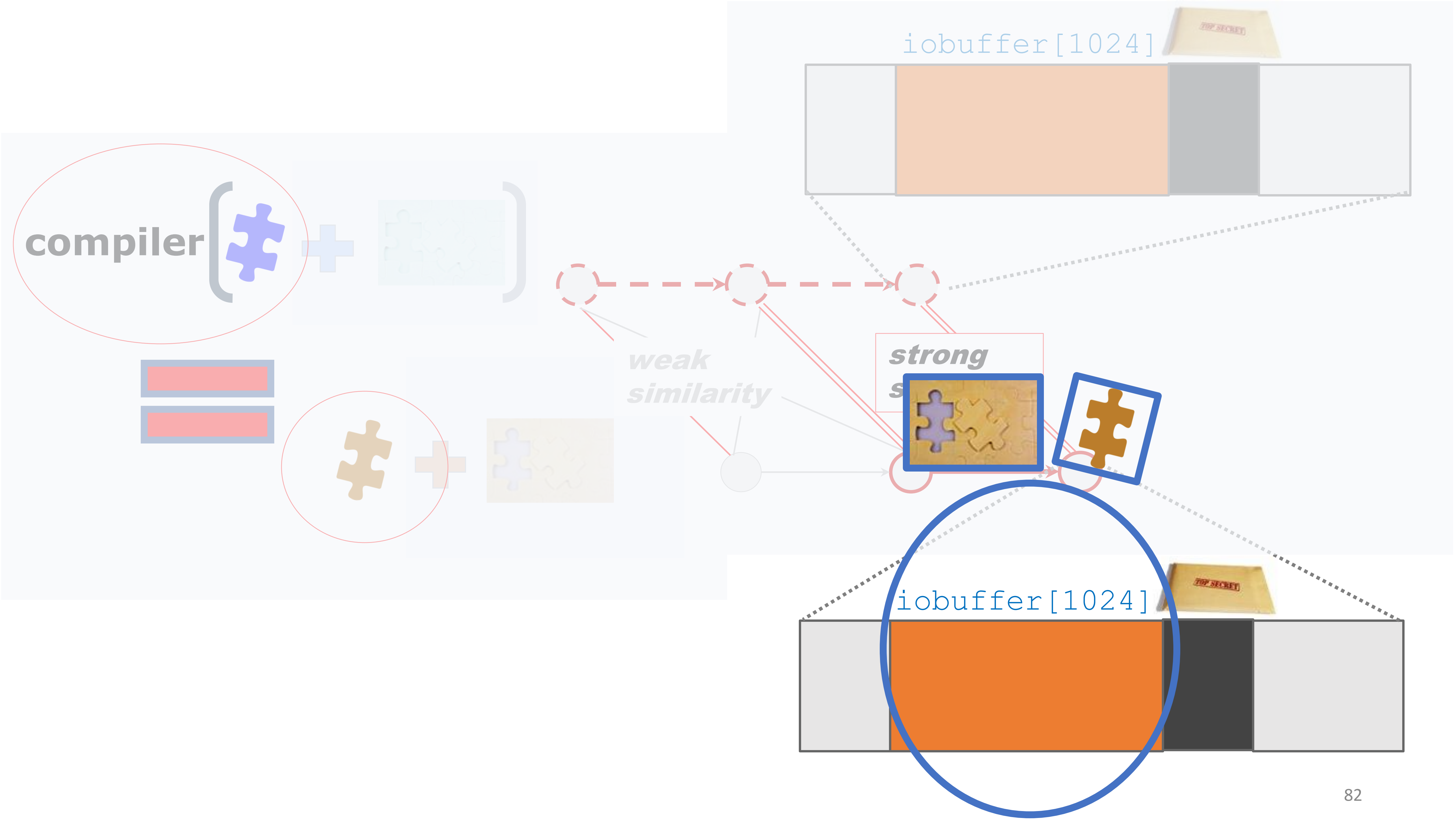
compiler
weak
similarity
strong
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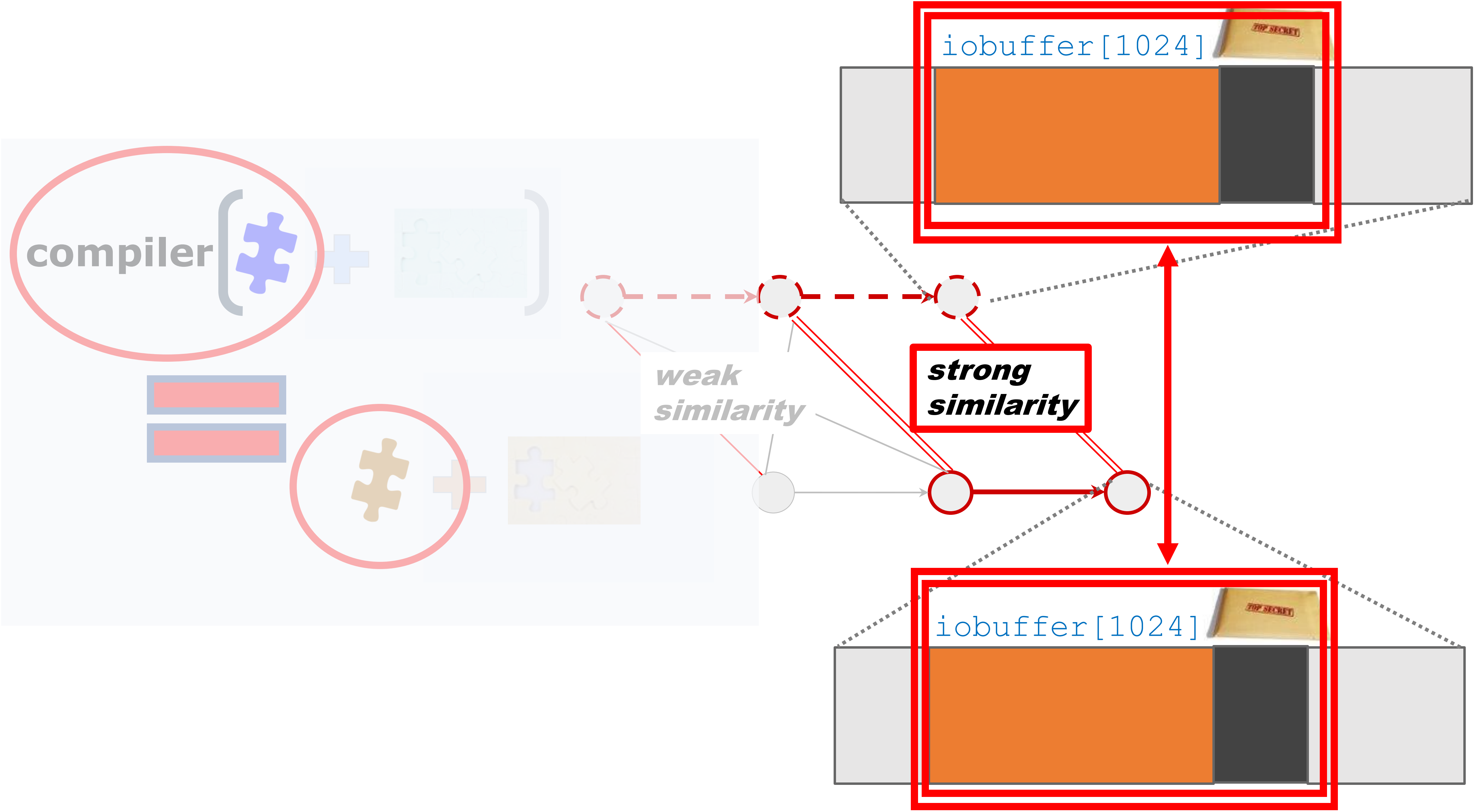
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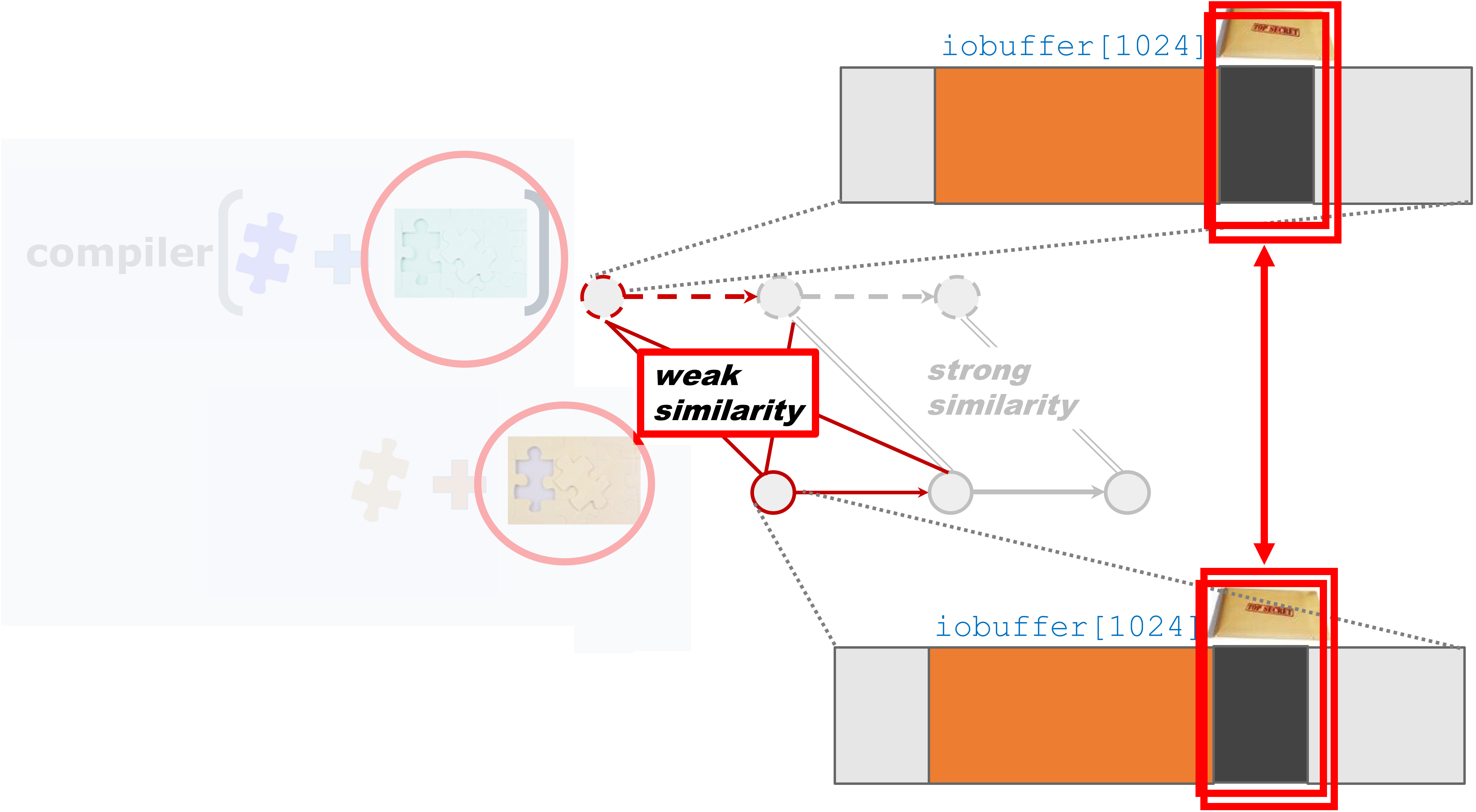
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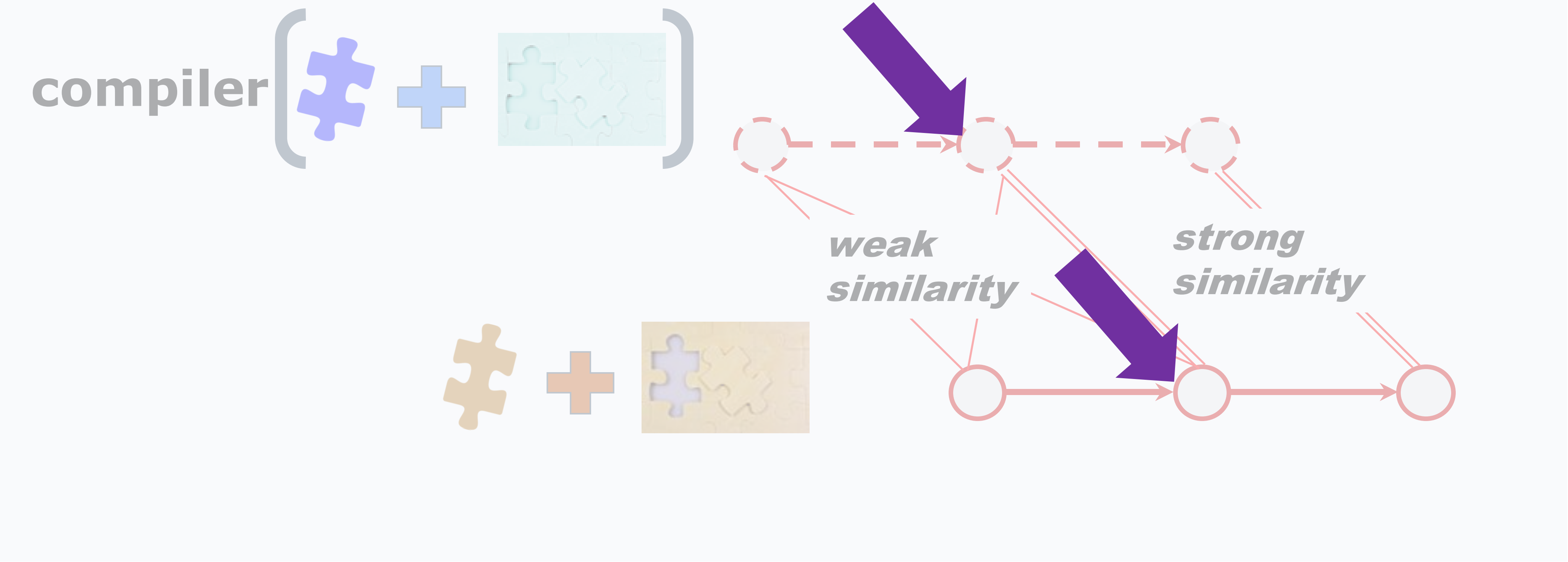
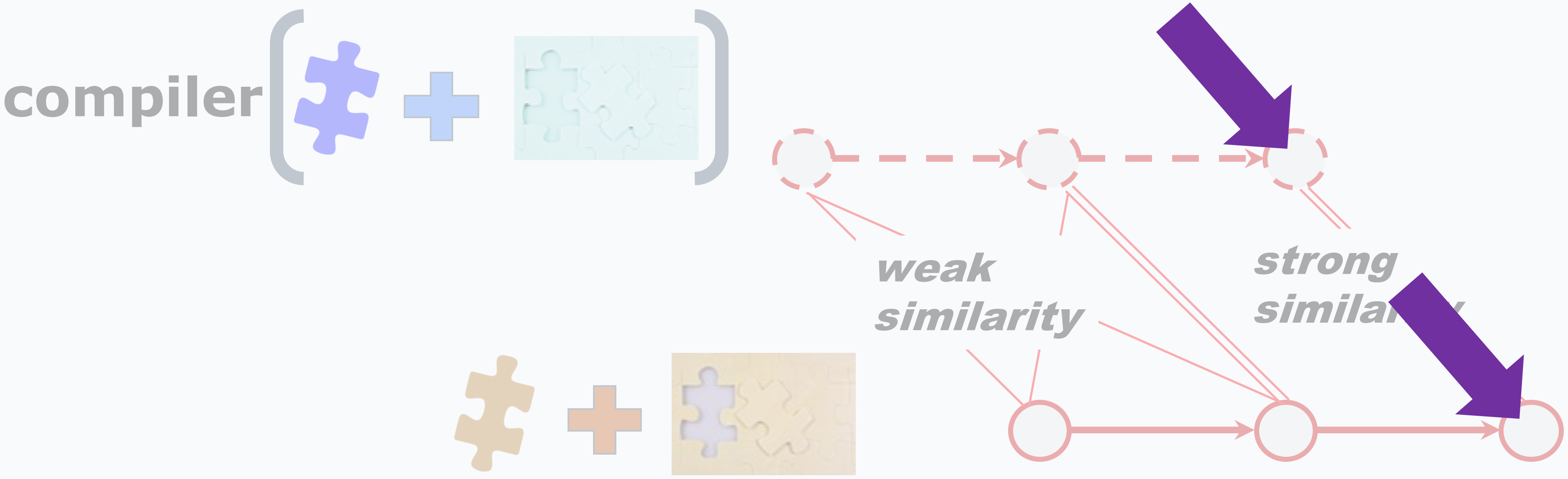
TOP SECRET

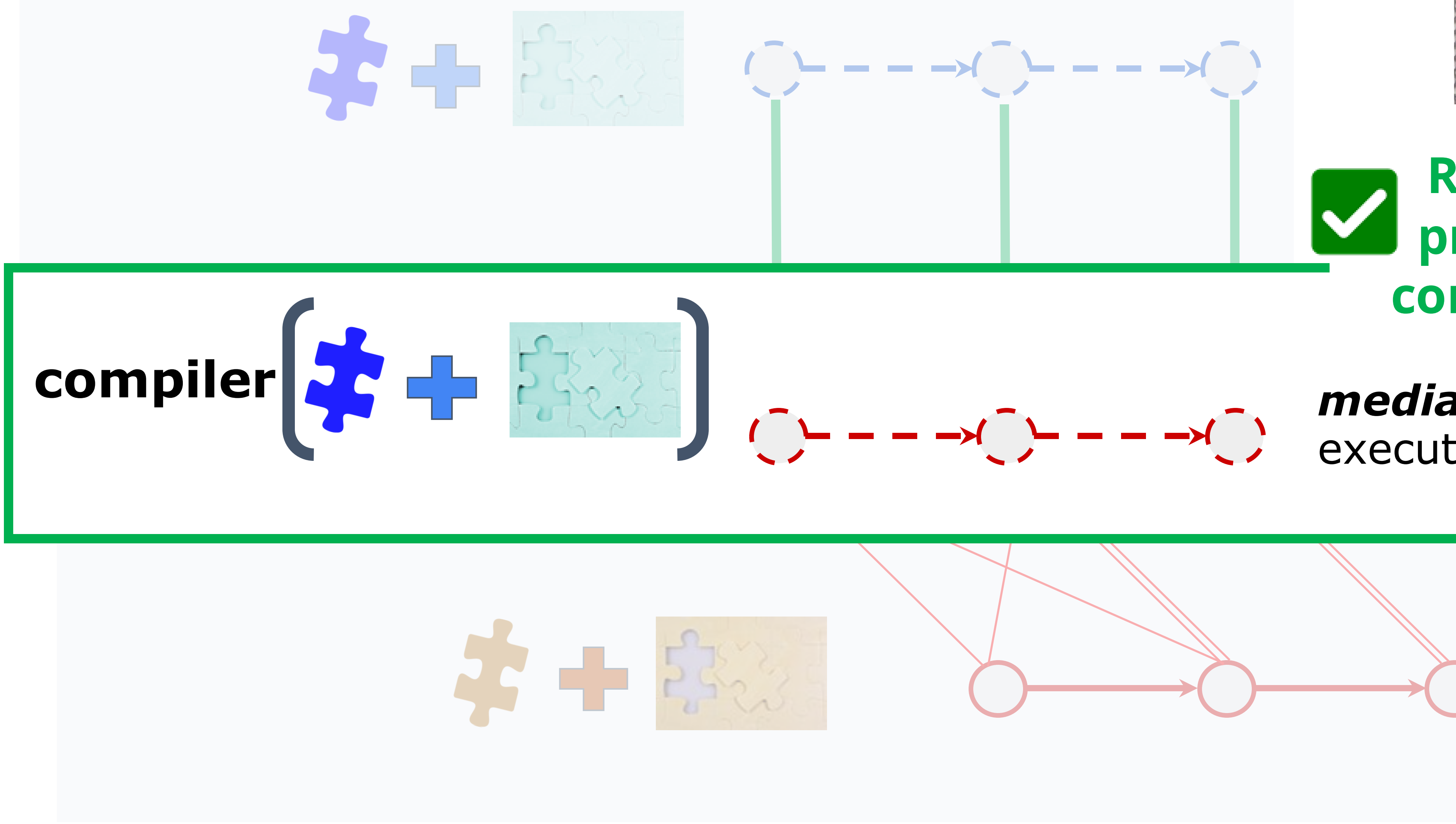
Strengthening lemma



Weakening lemma



Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")



✓ **Reuse the whole-program compiler correctness lemmas**

More in the paper

Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")

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Trace-directed
Back-translation

example

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Novel proof technique (called TrICL "/ˈtrɪk(ə)l/")

Trace-directed Back-translation example

Summary: In **CapablePtrs**, we present a proof of compiler full abstraction that achieves **reuse of the compiler correctness lemmas** while allowing **memory sharing through pointer passing.**