Client-Specific Equivalence Checking

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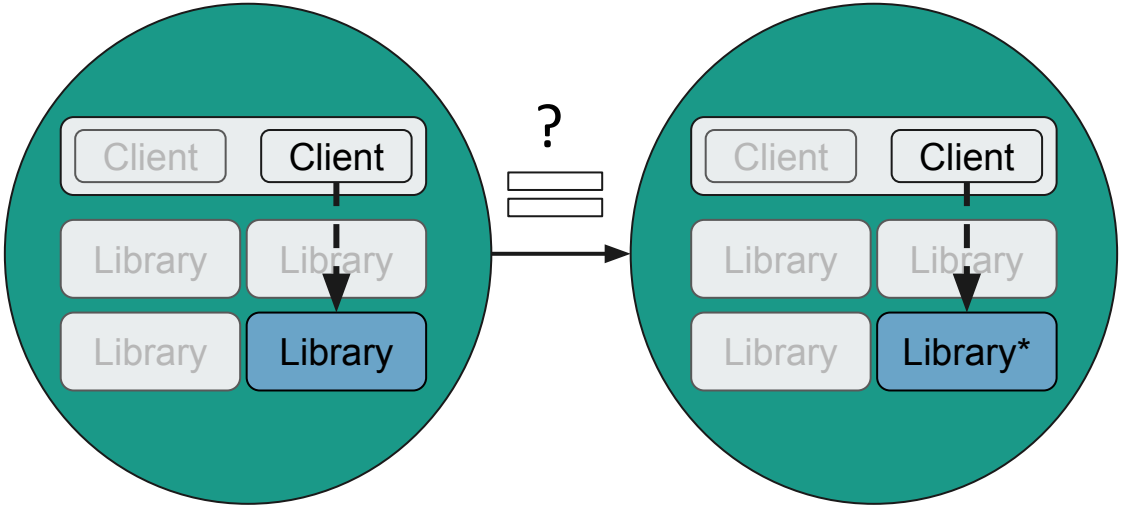
Motivation

Software

- is composite,



uses

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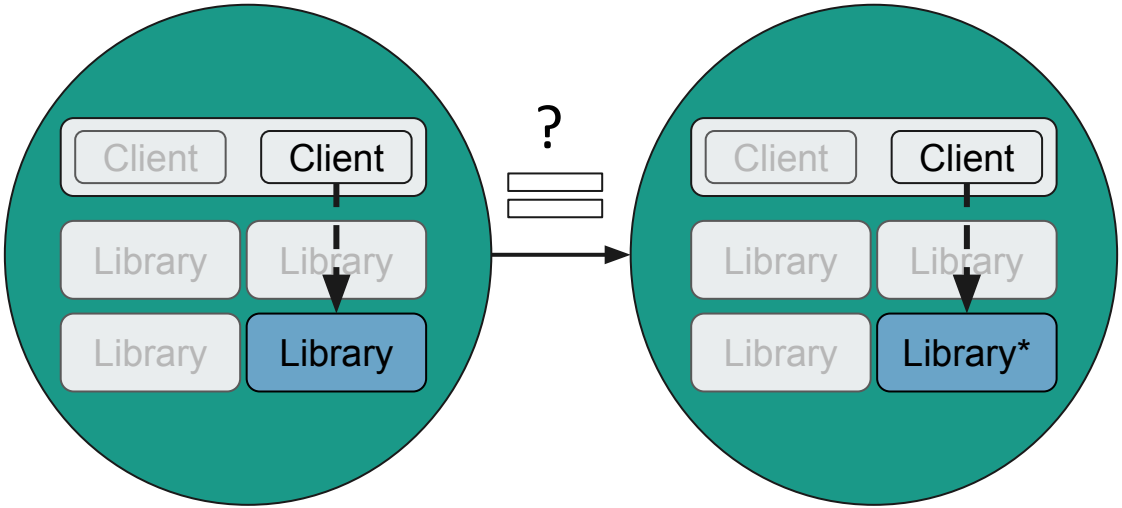

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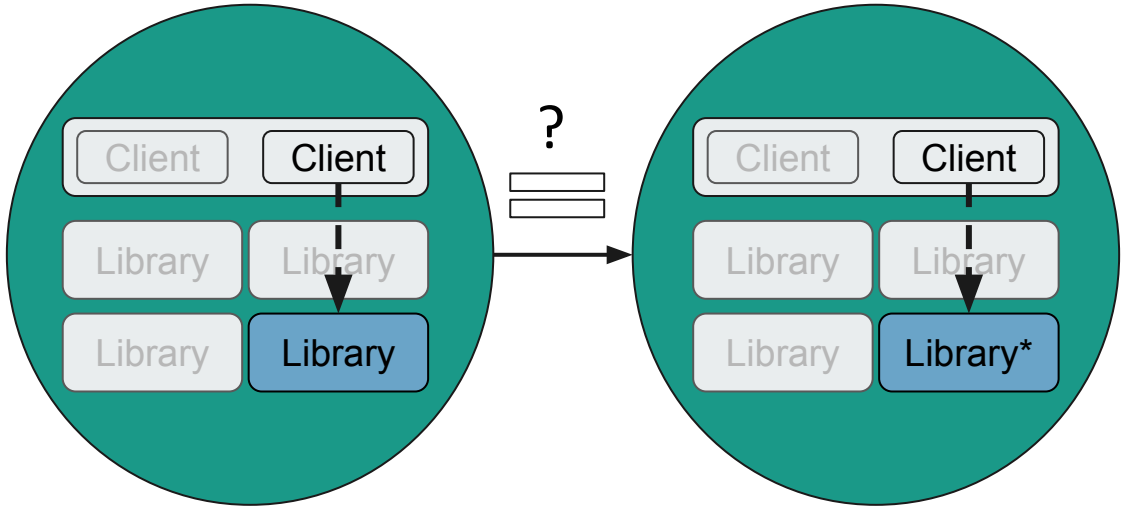

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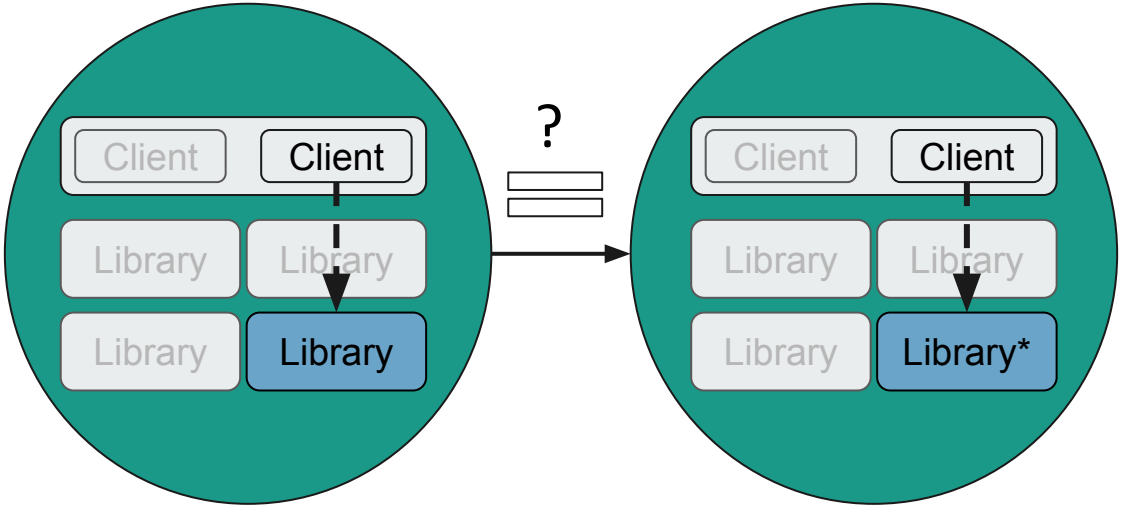

Example

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«Arithmetic without limitations»

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double mpf_get_d_2exp(signed long int *expptr, mpf_srcptr src) {
  mp_size_t size, abs_size;
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  int cnt;
+double d;

  size = SIZ(src);
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  }
  ptr = PTR(src);
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Library with changes

New version always returns positive number

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REAL log_real(REAL x) {
  double d;
  double ln_app;
  signed long int exp;

  d = mpf_get_d_2exp(&exp, x.get_mpf_t());
  ln_app = (double) exp *log(2.0) + log(d);
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  long *exp, F_mpz_poly_t poly, double val)
{
  ... res = mpf_get_d_2exp(exp, output);
  // work around bug in earlier versions of GMP/MPIR
  if ((mpf_sgn(output) < 0) && (res >= 0.0))
     res = -res;
  ...
}
```

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Takes absolute value of output

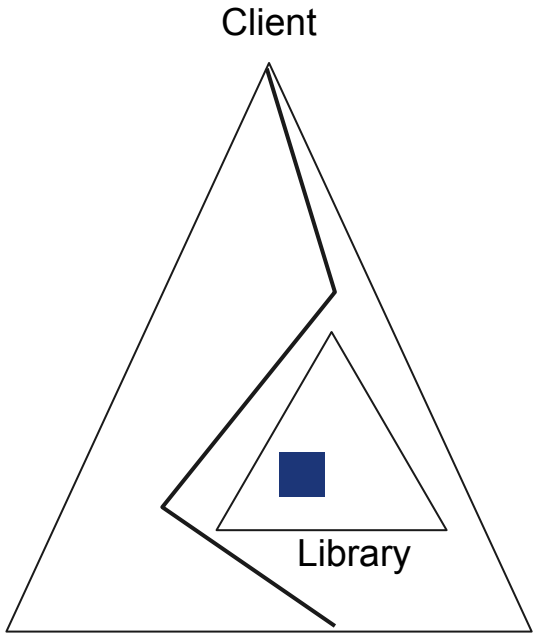
Can we efficiently detect when a client is affected by a library update?

First Attempt: Apply Existing Techniques.

Preliminaries

We consider partial functional equivalence

- Loops and recursion (implicitly) unrolled to configurable depth, d
- Two unrolled programs P, P’ are equal iff for all x, P(x) = P’(x)



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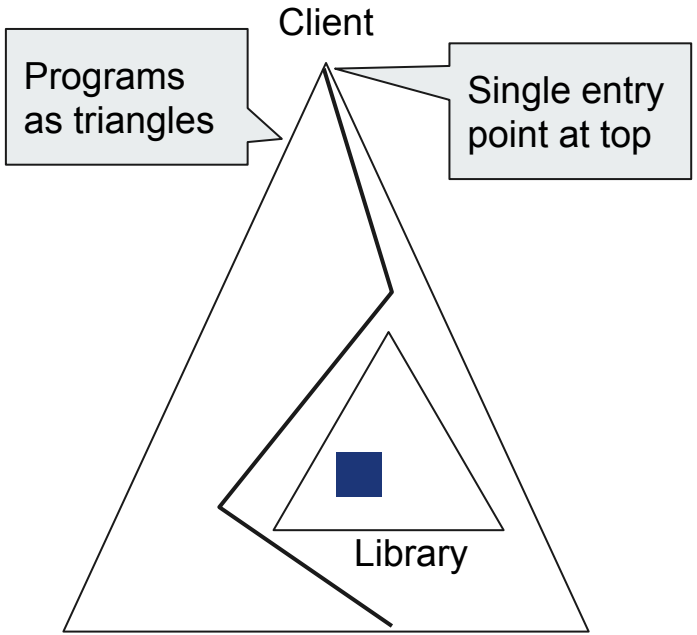

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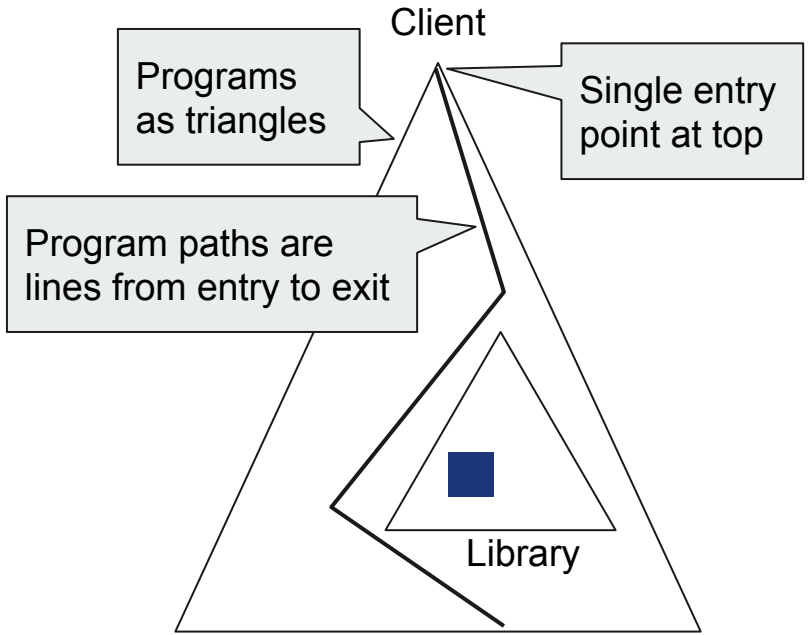

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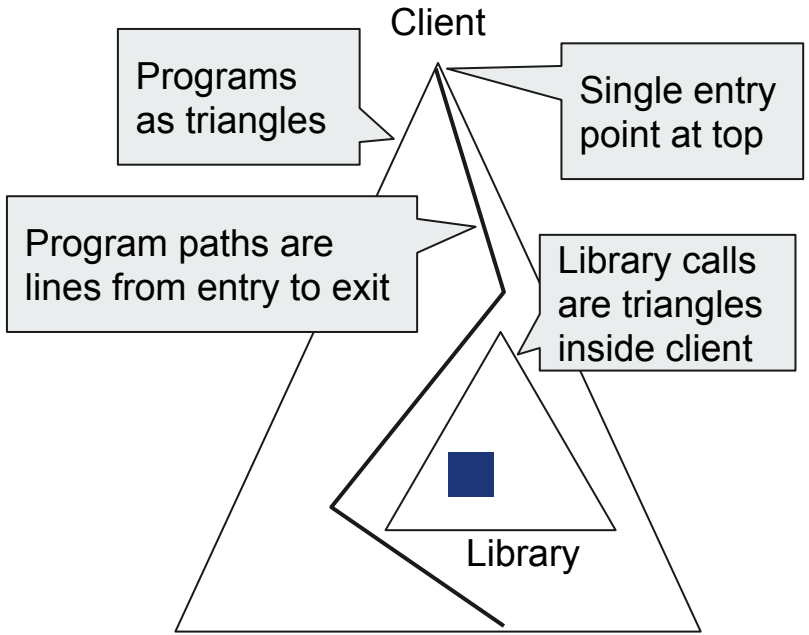

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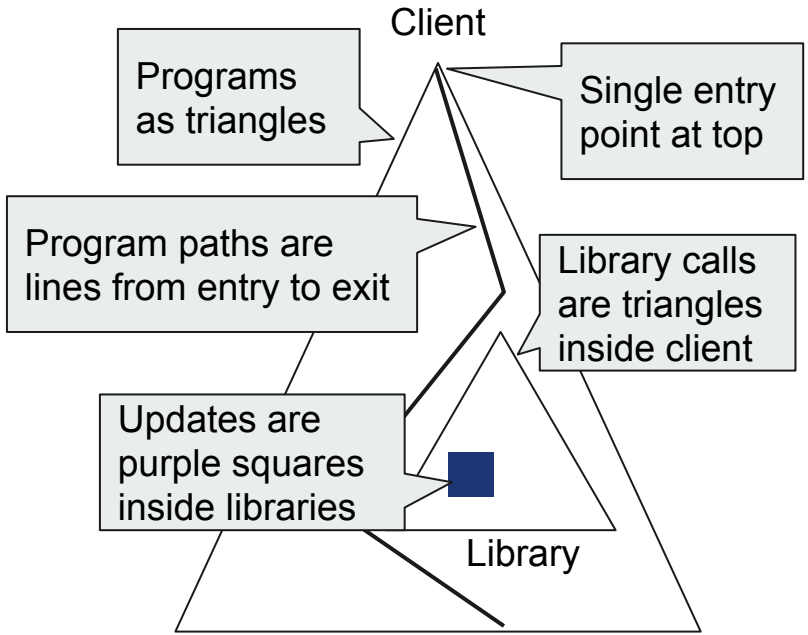

Example Diagram

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      if (x>=18 && x<22)
            return foo(x,20);
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int foo(int a, int b) {
      int c=0;
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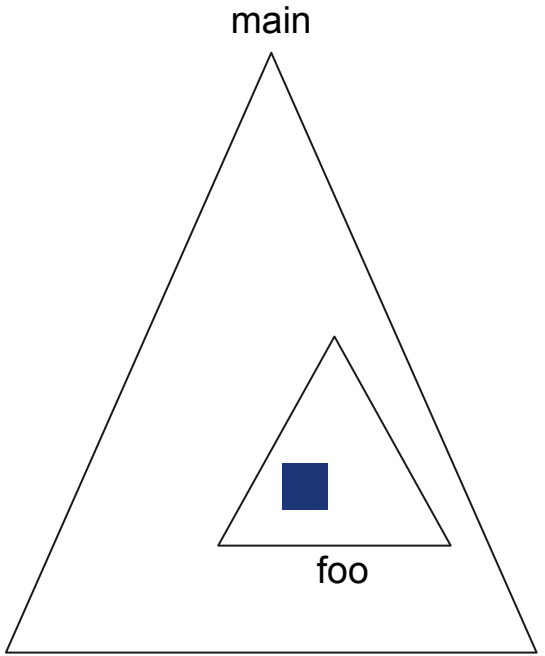
[Trostanetski et al, 17]



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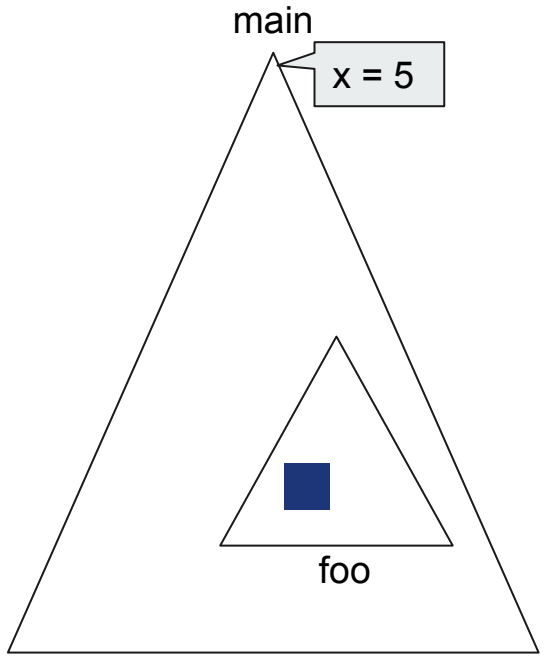

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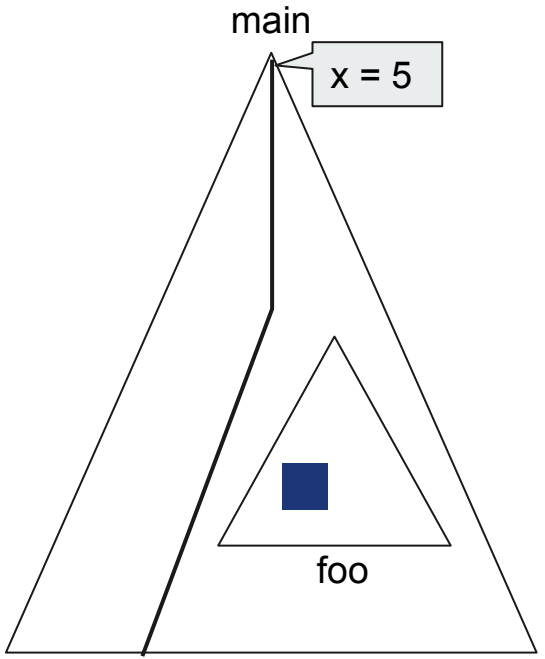

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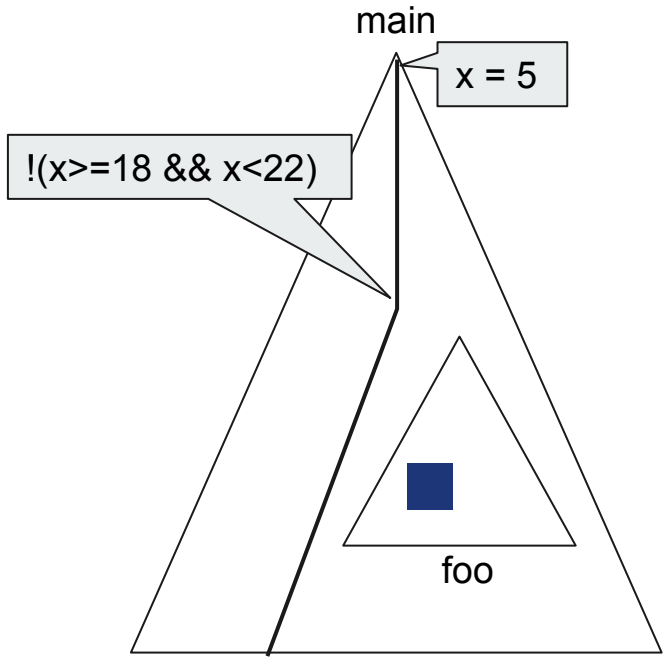

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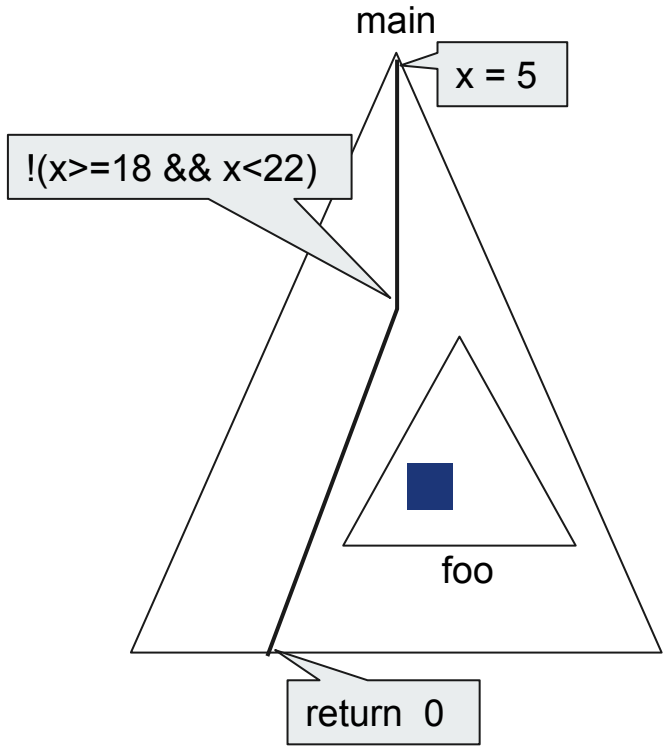

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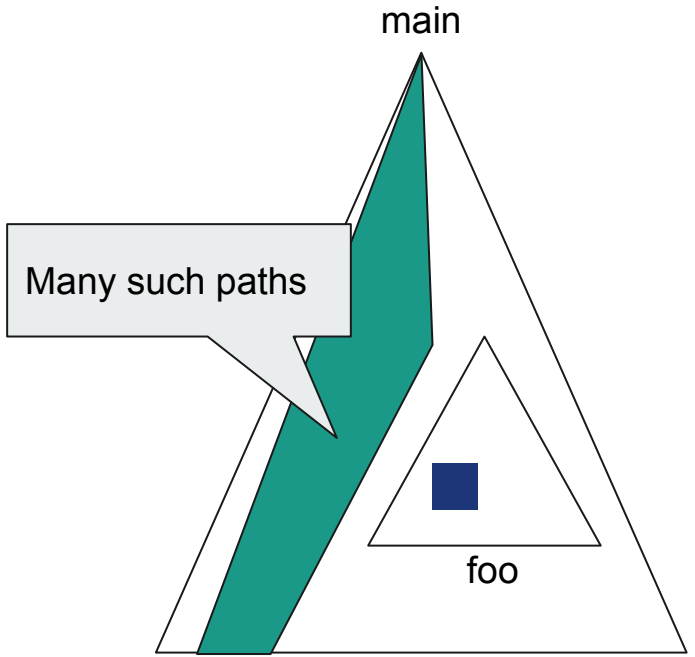
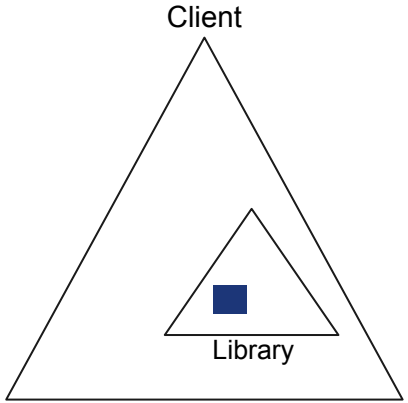
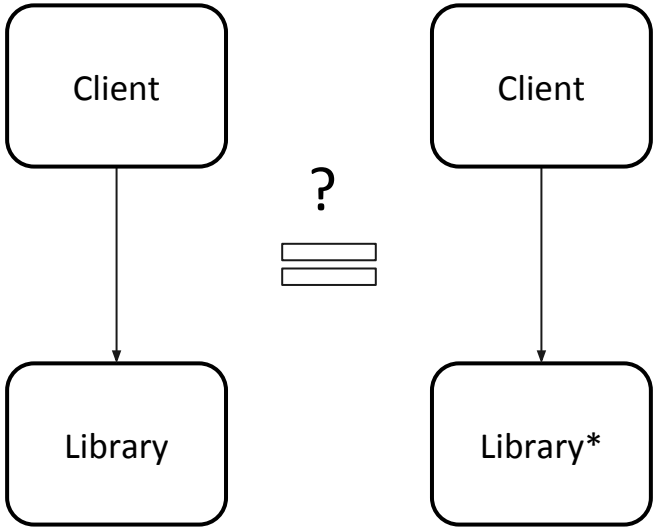


Different Ways to Apply Existing Solutions





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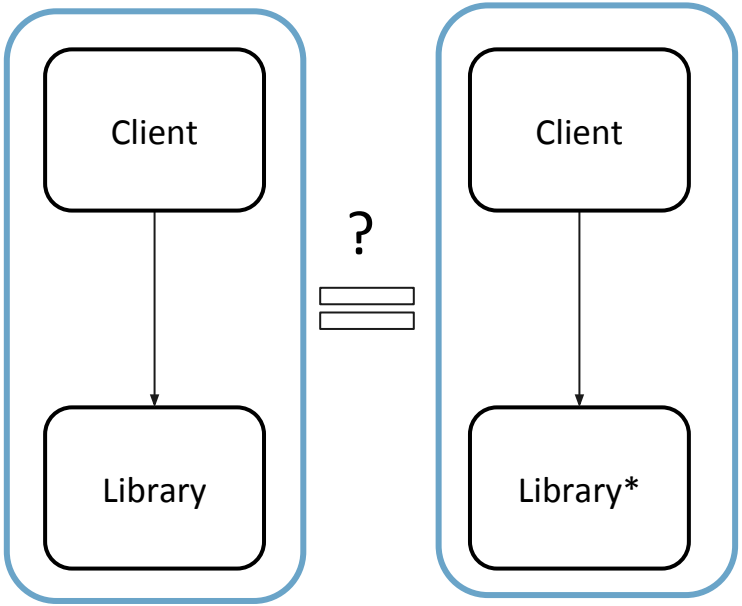

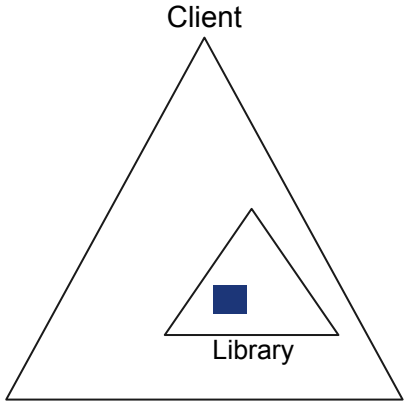

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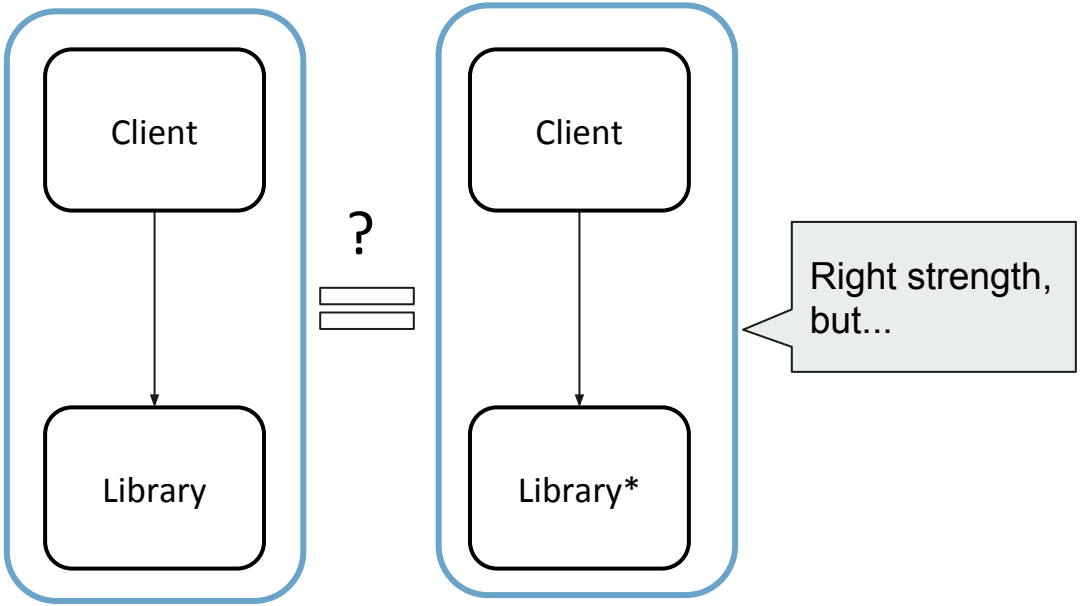

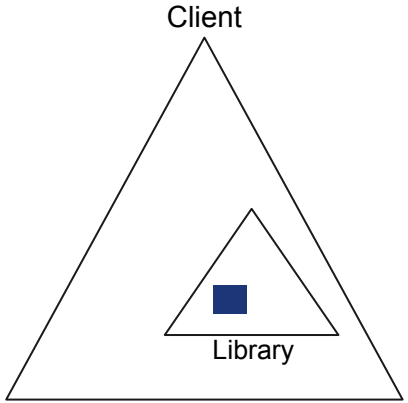

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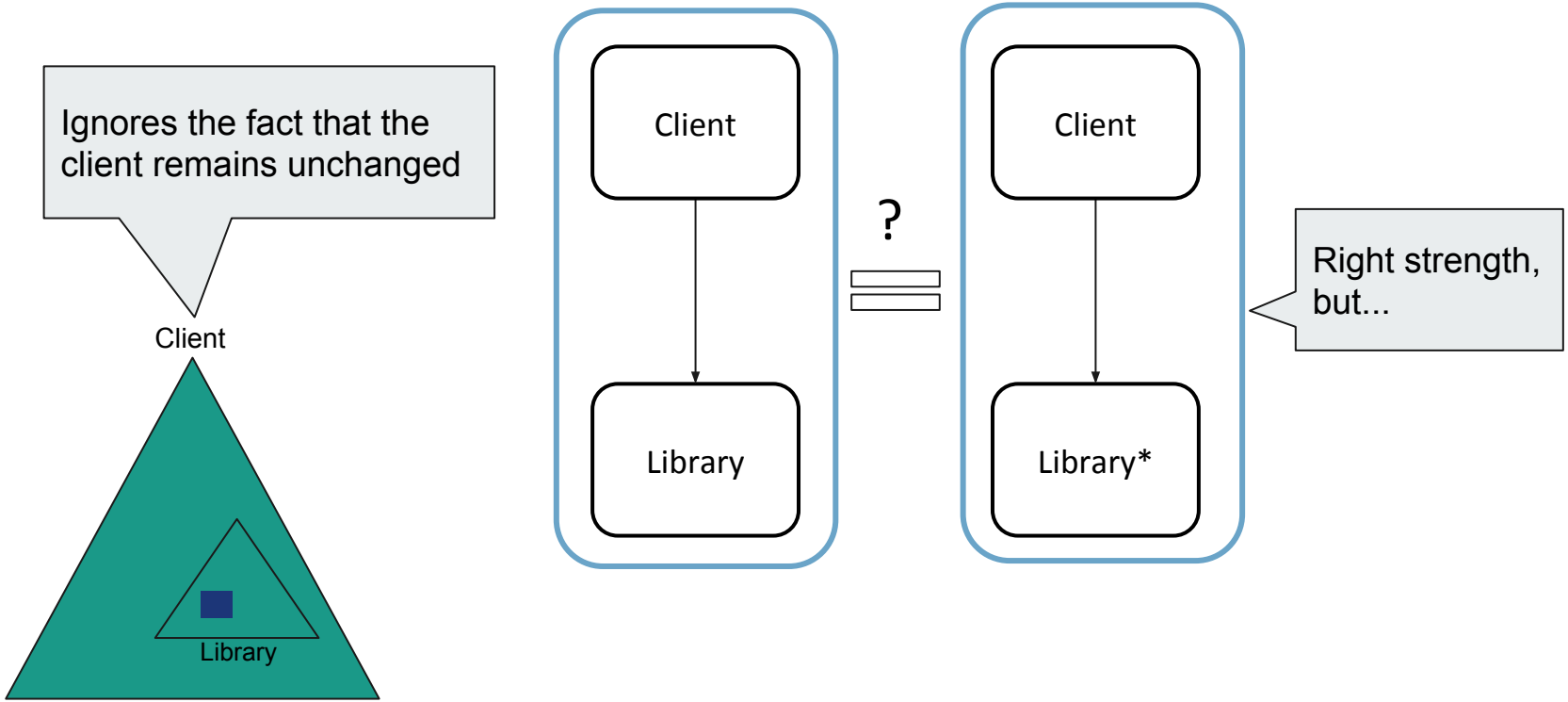
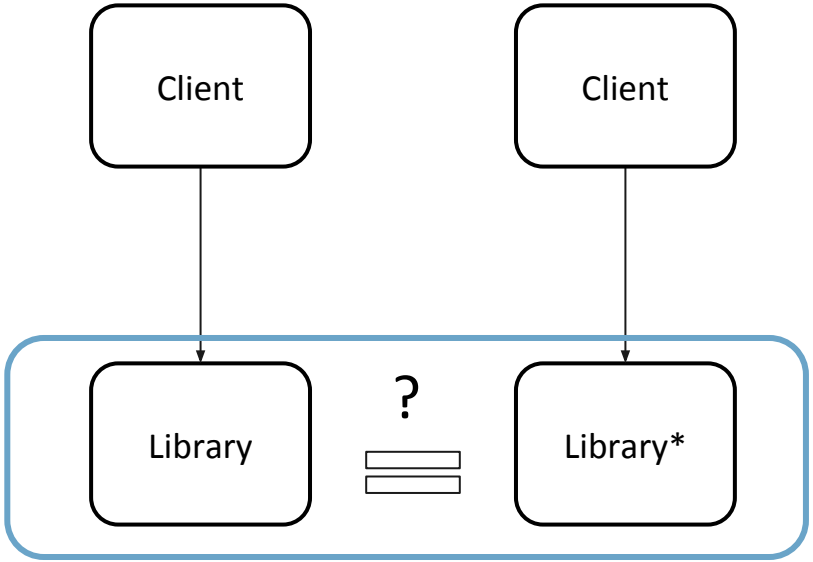
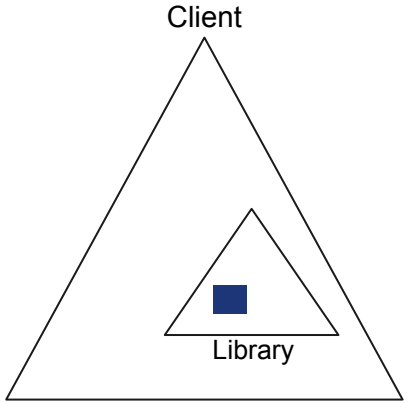


Different Ways to Apply Existing Solutions

2. Checking Equivalence of Libraries





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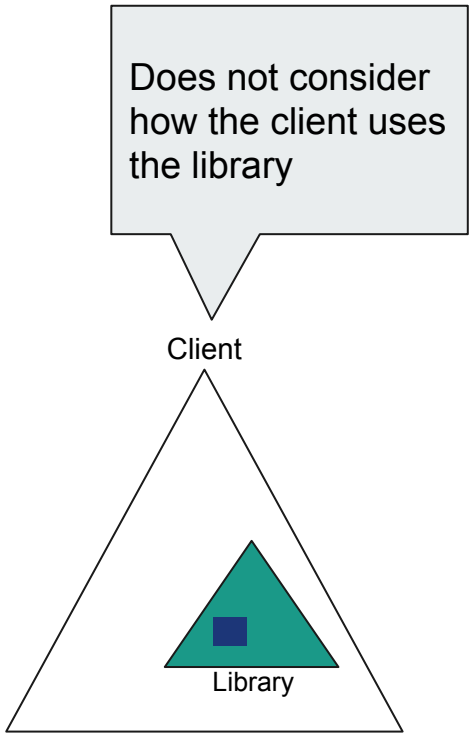

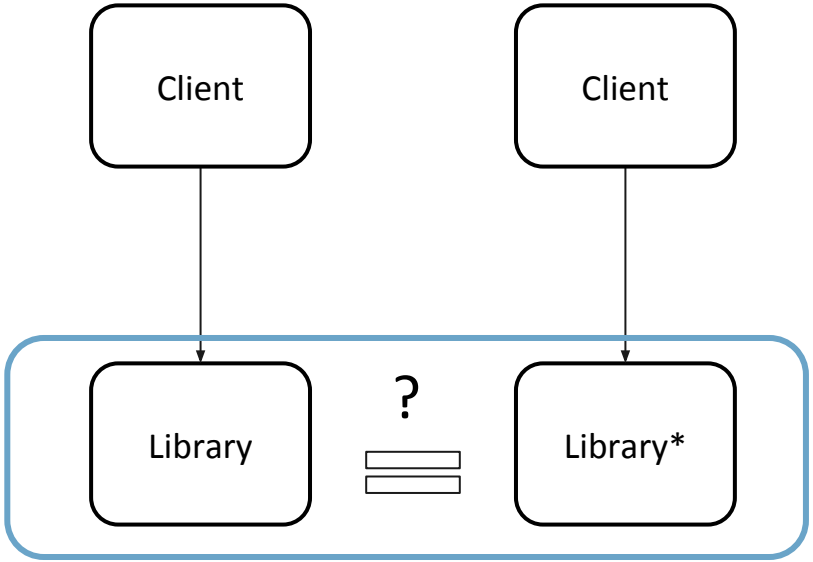

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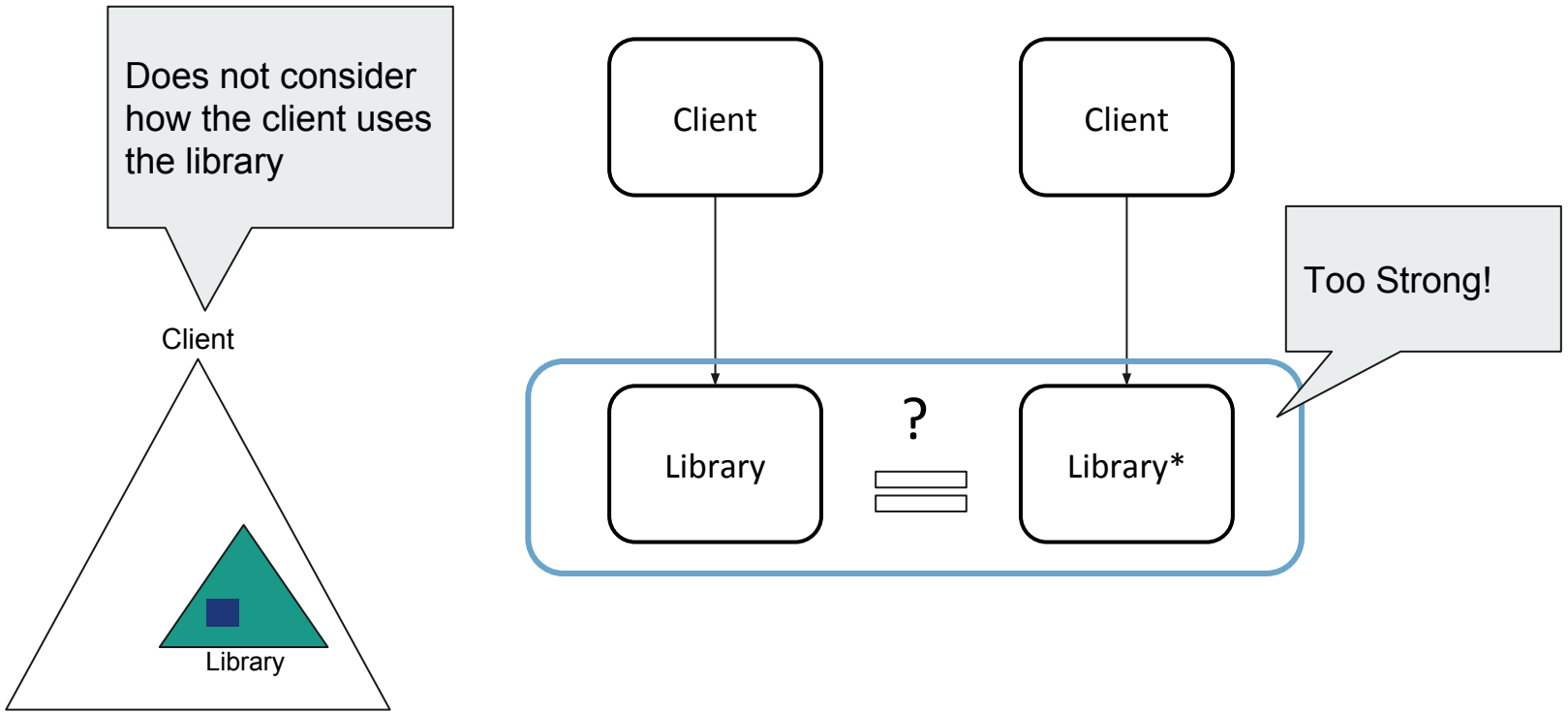

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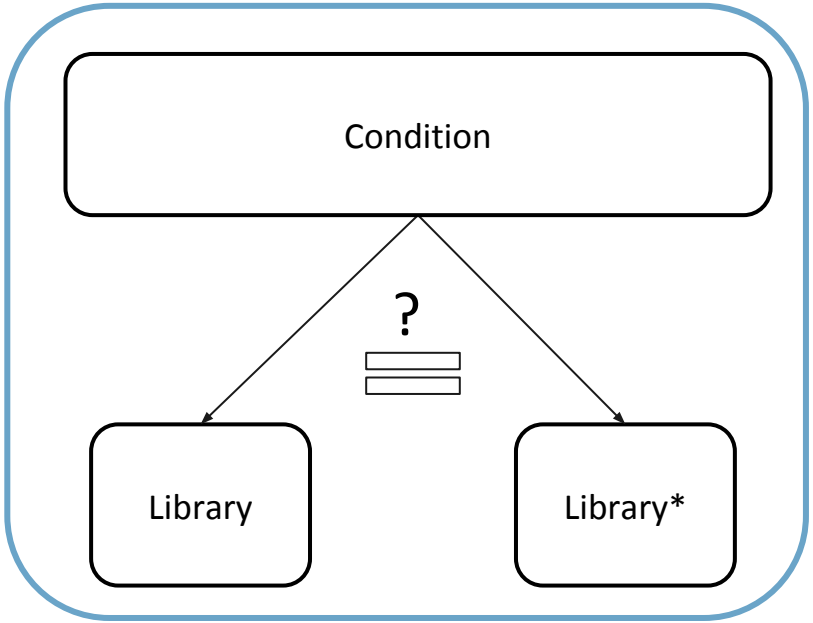

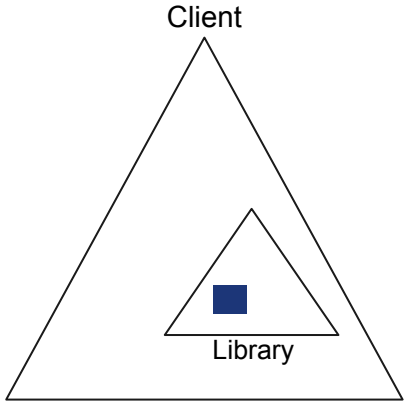

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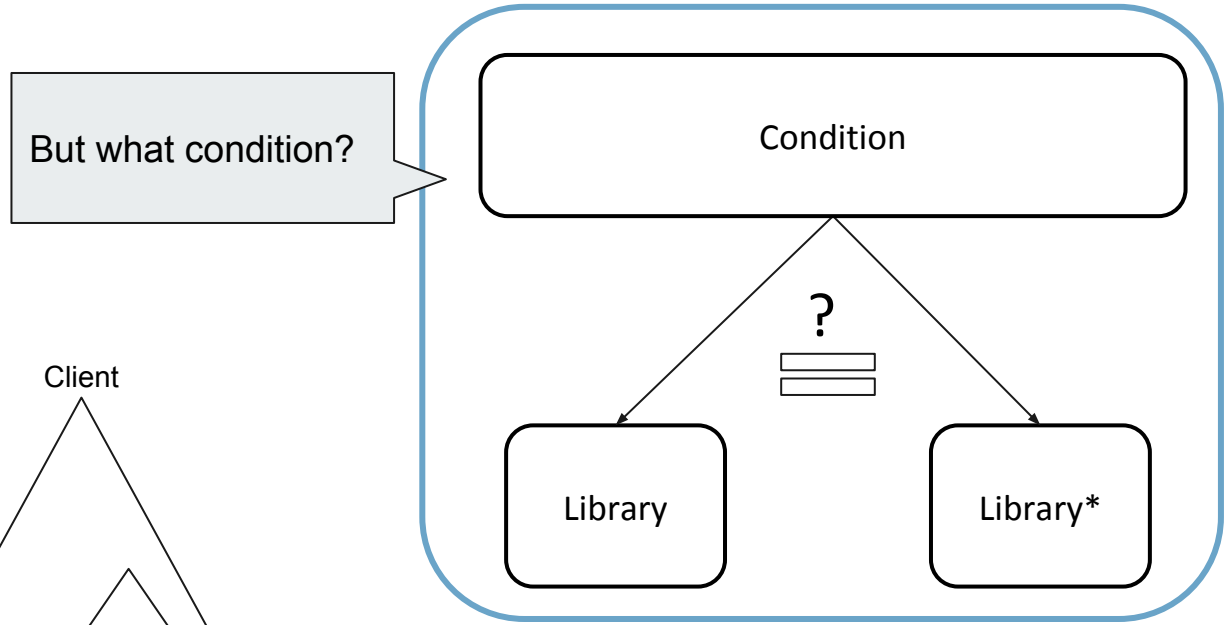

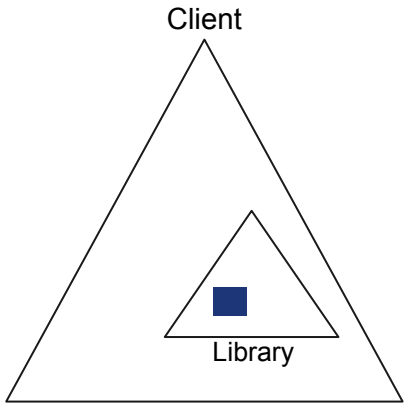

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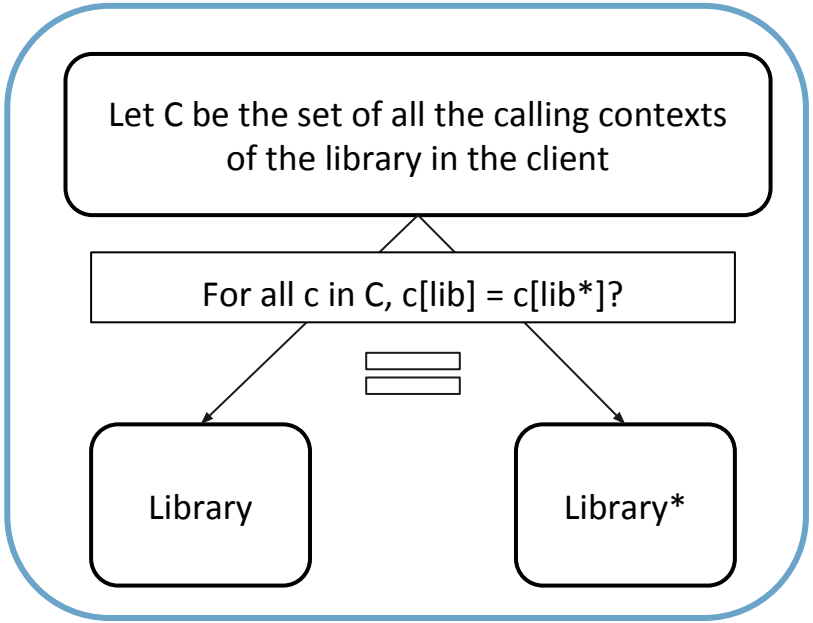

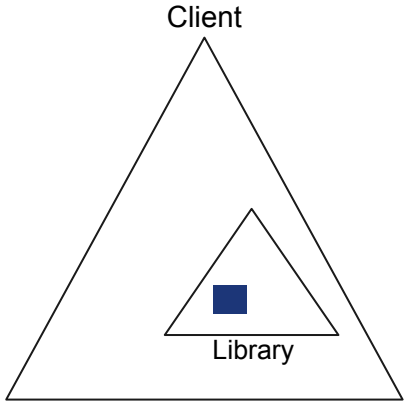

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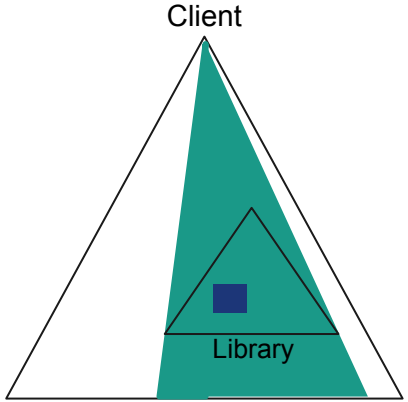
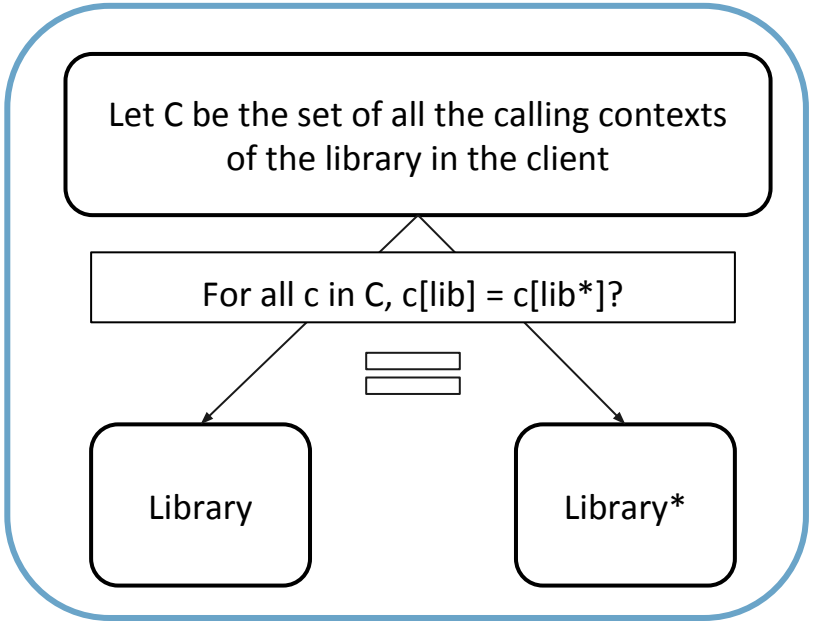
3. Checking Equivalence Of Libraries Under a Condition

Exploring part of client that calls library, and part of library used by client





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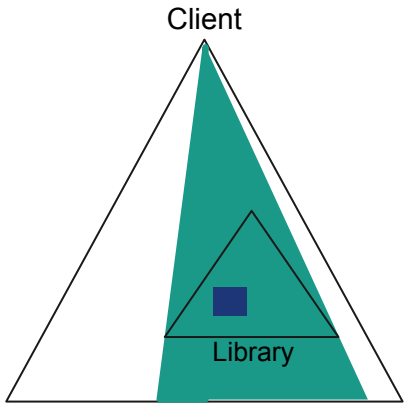


Let C be the set of all the calling contexts of the library in the client

For all c in C, c[lib] = c[lib*]?

Library

Library*

But too strong again!

- lib(x) := x
- lib'(x) := -x
- client := lib(1) + lib(-1)

Can we efficiently detect when a client is affected by a library update?

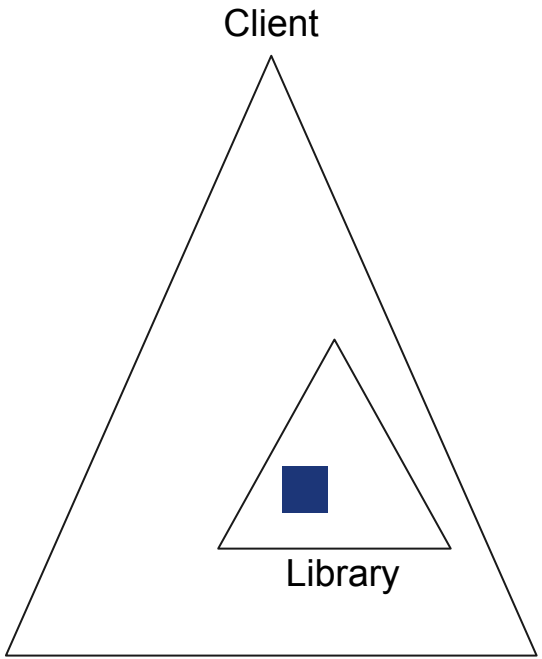
Second Attempt: CLient-Specific EquiValence CheckER

CLEVER Overview

Insight: existing techniques are too strong, or consider too much.

To get the most precise and efficient analysis let's consider only

- how the client uses the library and
- where the library change is active



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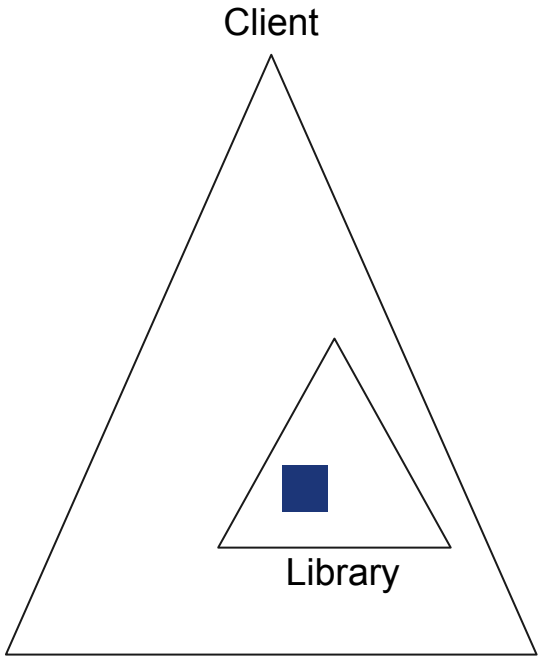
- Identify when a client doesn't use the library change
- When it does, look for quick counterexample



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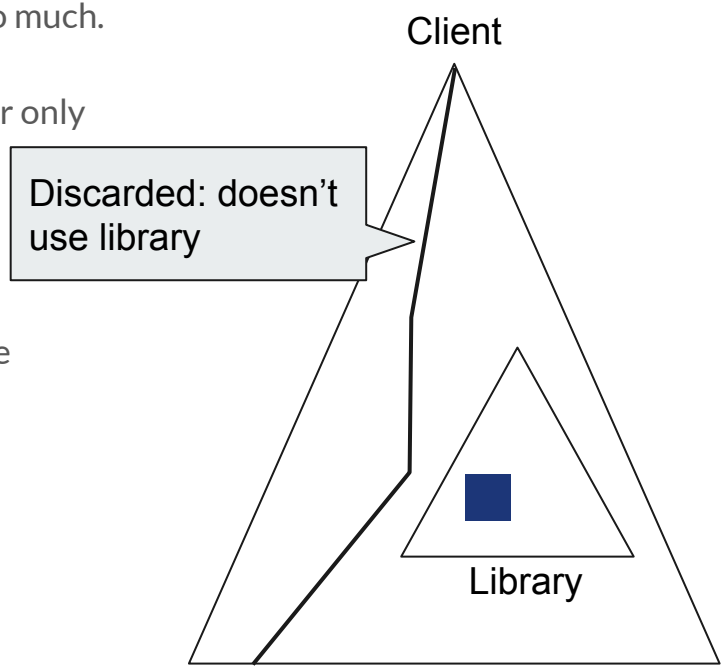

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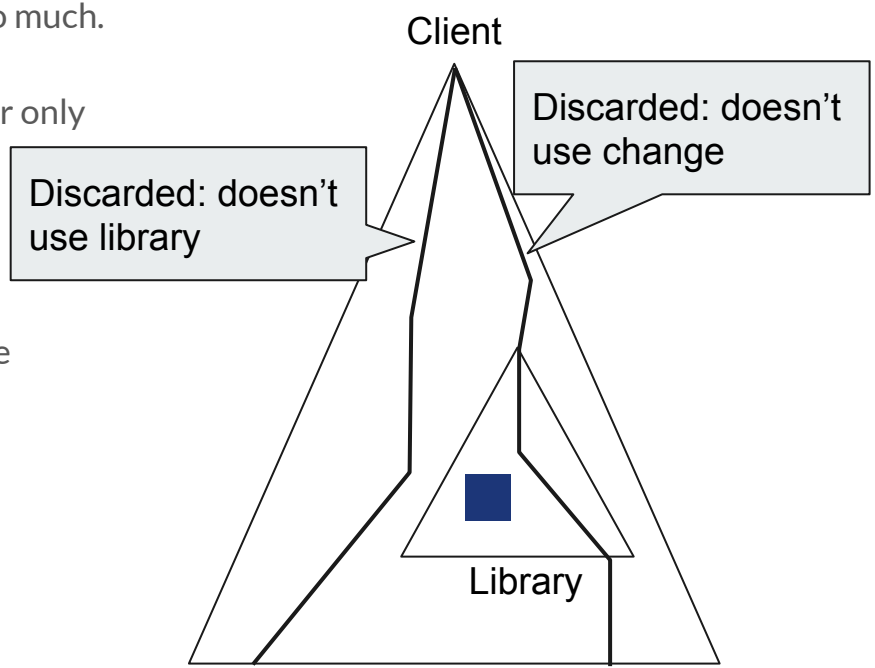

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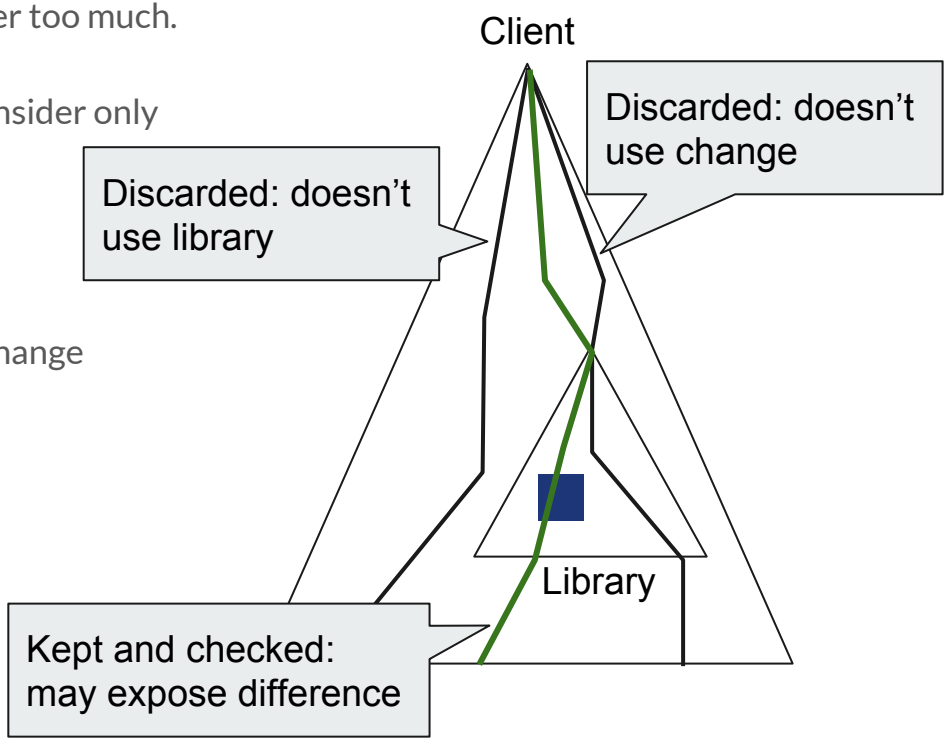

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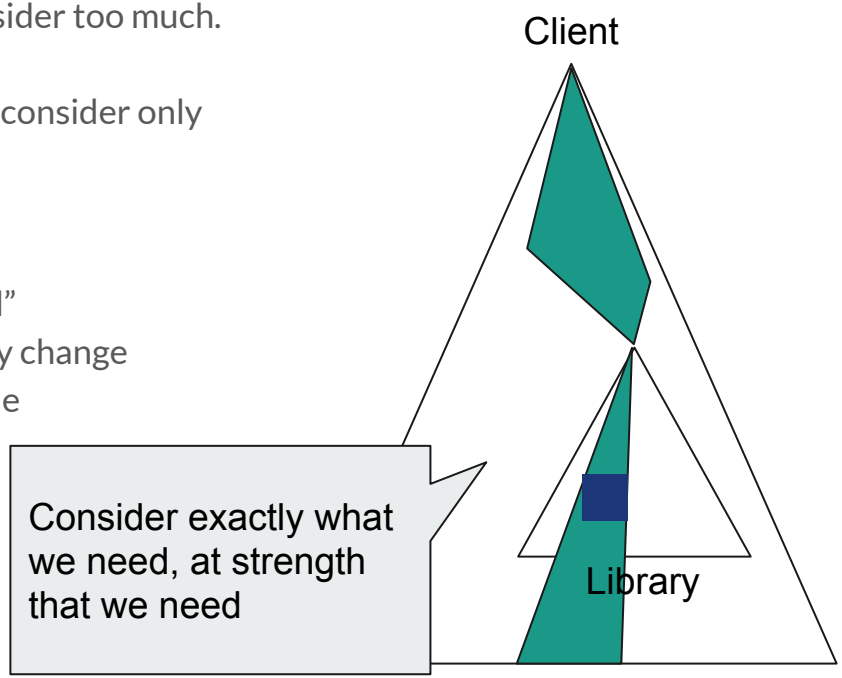
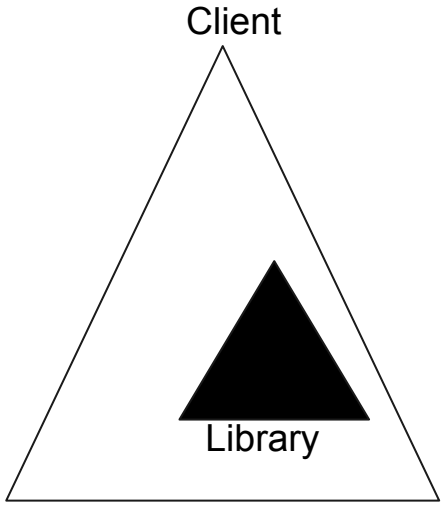


CLEVER In Detail

Algorithm

- Explore Client with the library uninterpreted
  - Collect uses/contexts of the library



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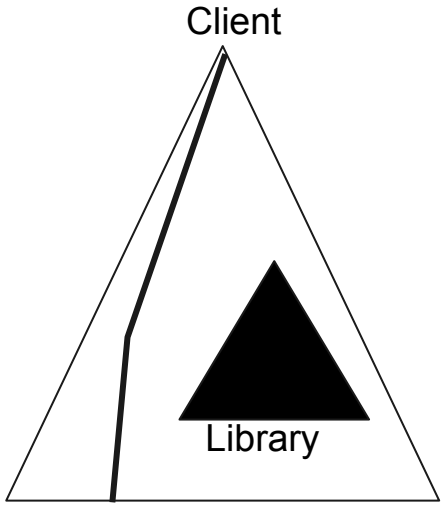

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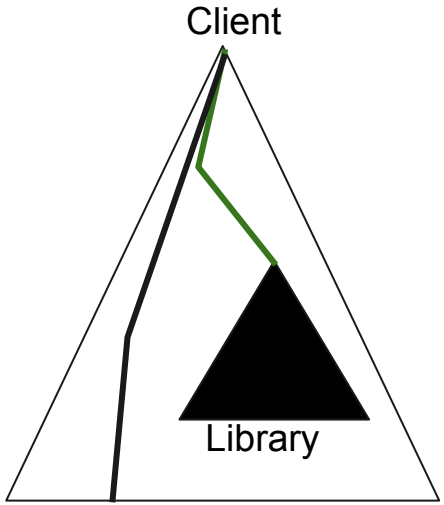

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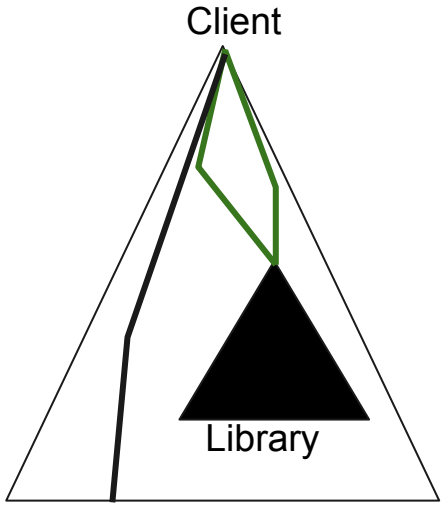

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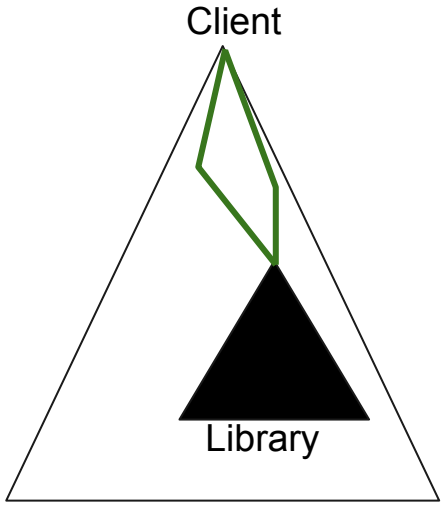

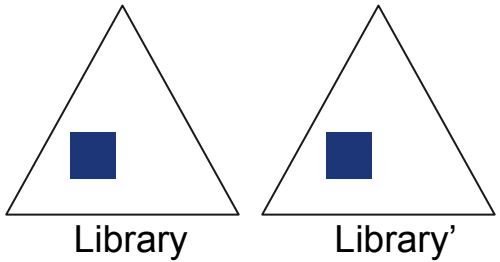

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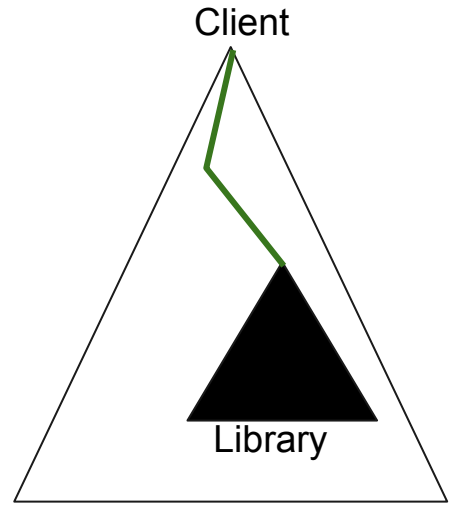

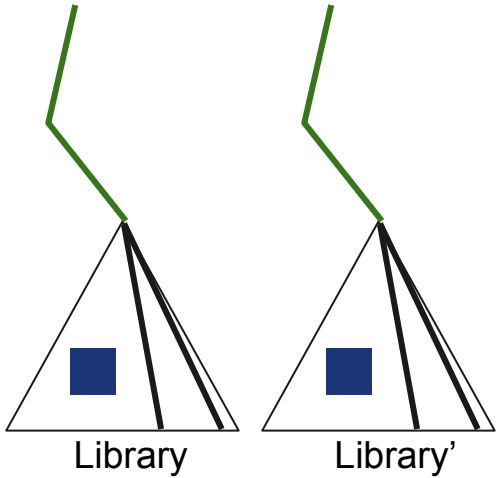

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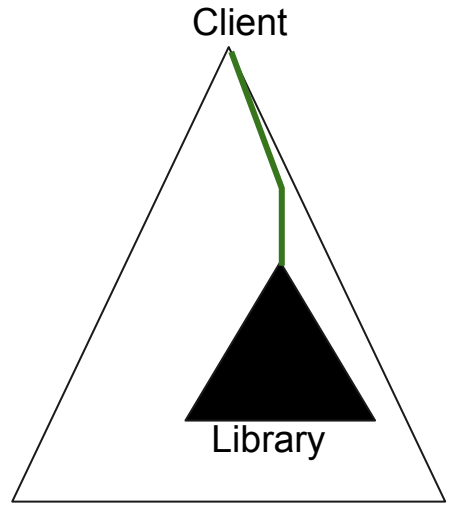

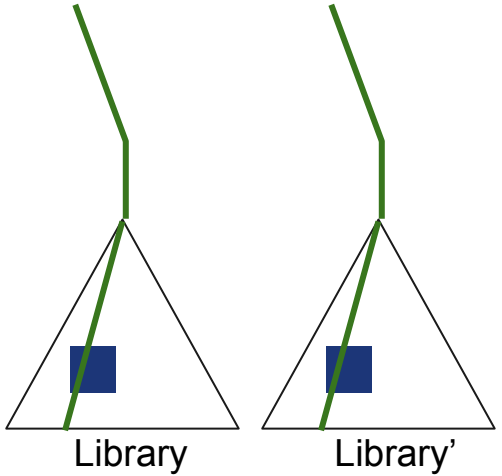

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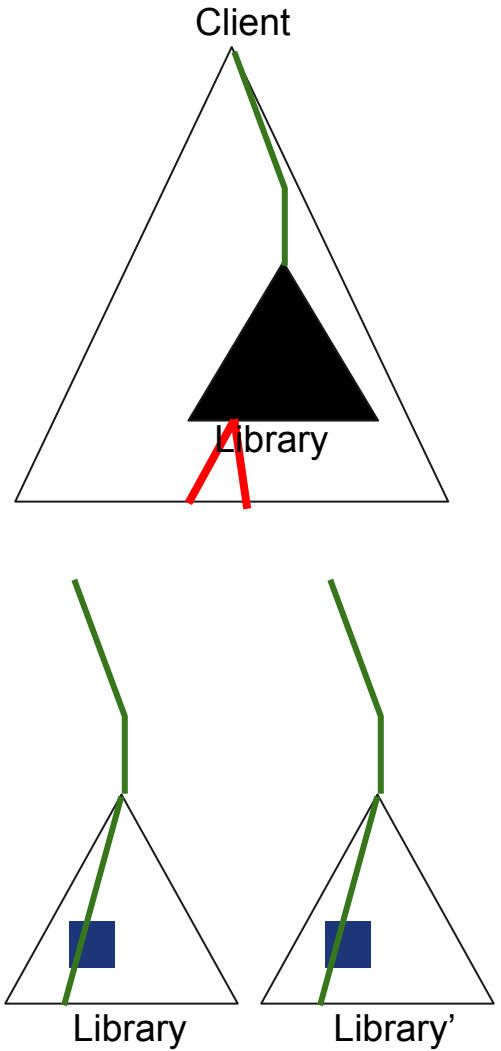

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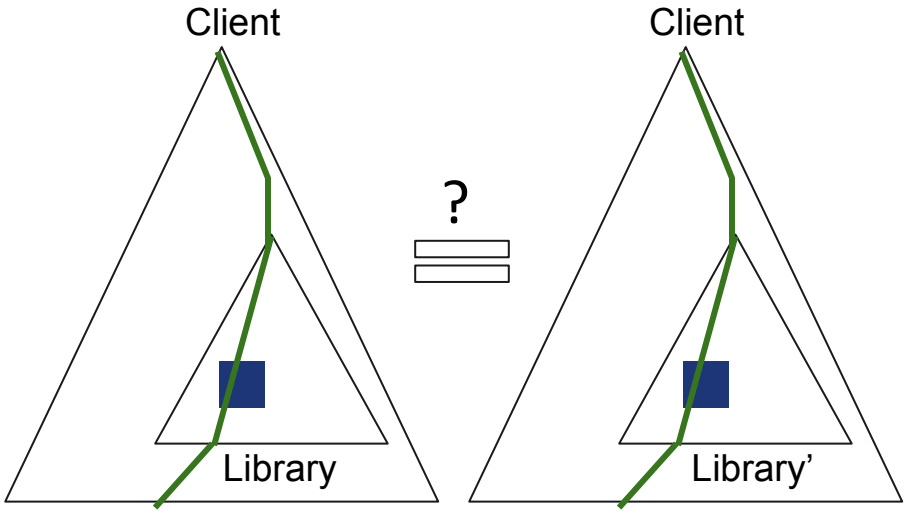
- Create equivalence assertion from stored paths
- Dispatch to existing verifier, or SMT solver



Example Savings

```
int main(int x) {
      if (x>=18 && x<22)
            return foo(x,20);
      return 0;
}

int foo(int a, int b) {
      int c=0;
-     for (int i=1;i<=b;++i)
-           c+=a;
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      return c;
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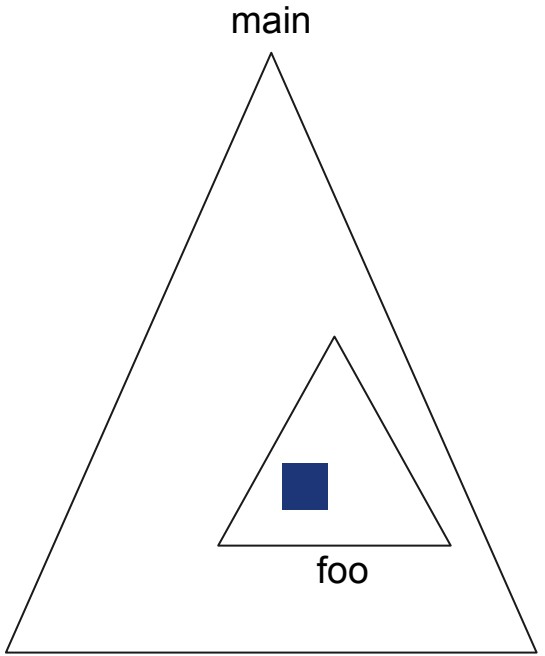
[Trostanetski et al, 17]



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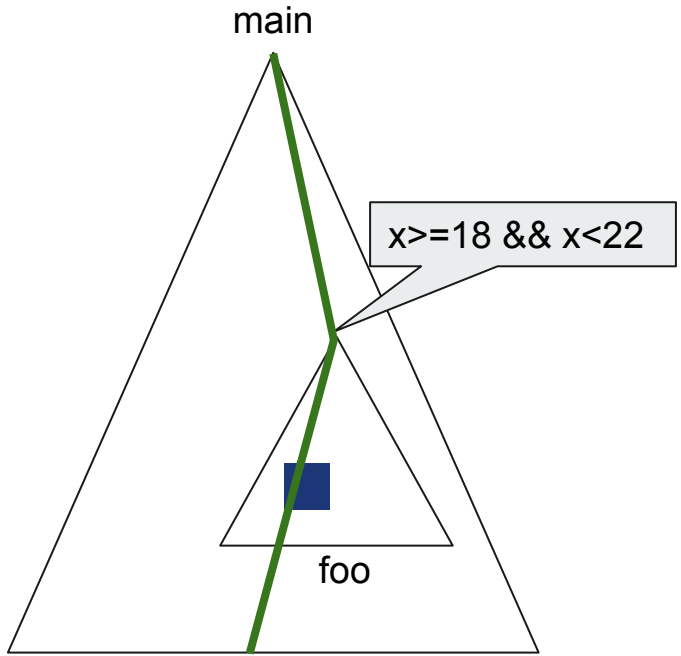

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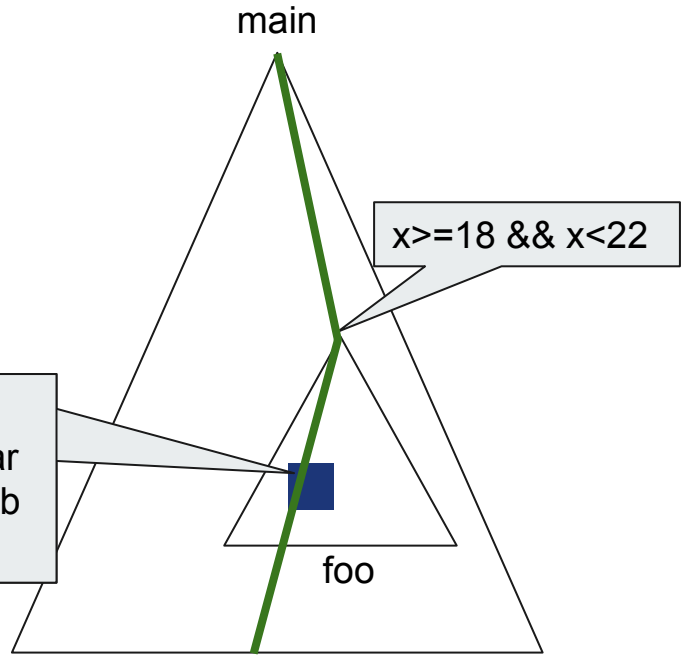
Saves us from computing a non-linear loop invariant: c == a*b == a'*b'



[Trostanetski et al, 17]

Evaluation

Implementation

Available at: https://github.com/Client-Specific-Equivalence-Checker/CLEVER

Explores client contexts using symbolic execution

- PyExSMT (https://github.com/FedericoAureliano/PyExSMT)

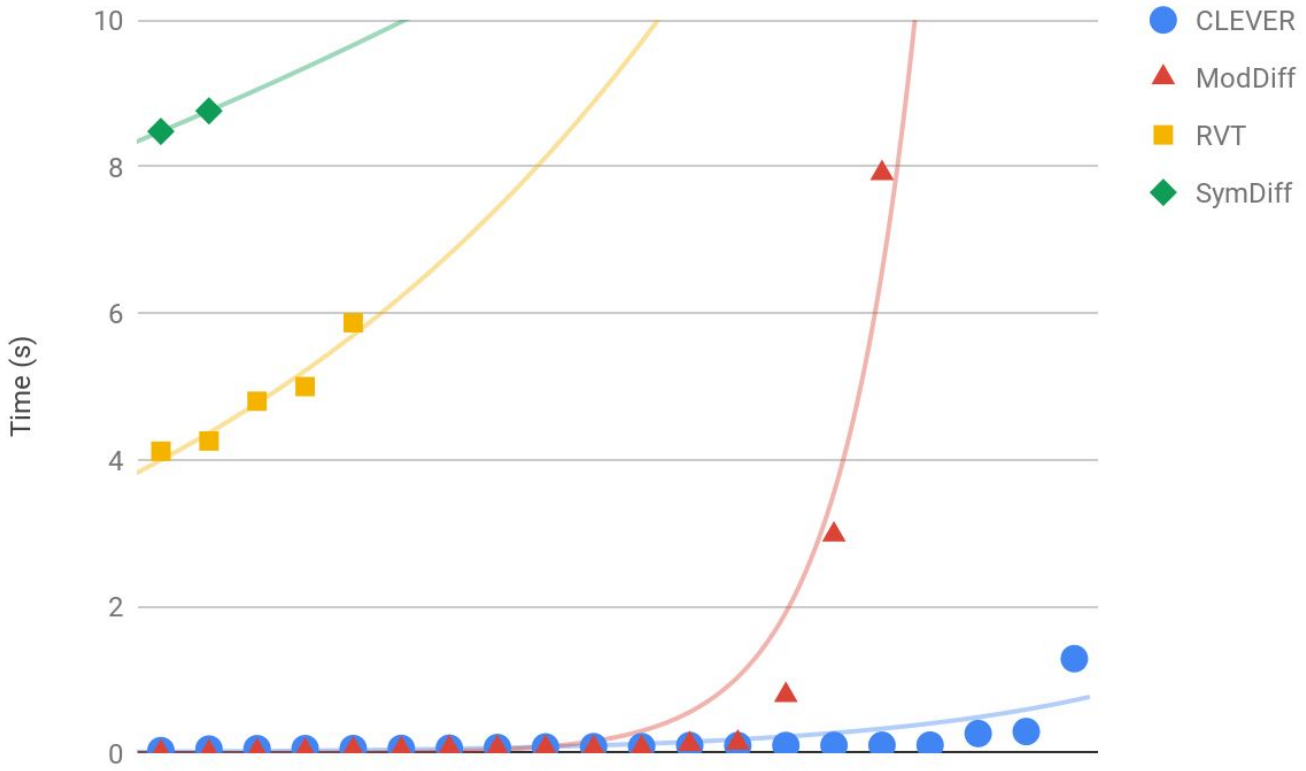
Experimental Setup

We compare with SymDiff, RVT, and ModDiff (treating client-lib pair as a whole).

Subjects:

- 39 client-library pairs with library updates (23 equivalent / 16 inequivalent)
- 23 come from the ModDiff suite (small programs)
- 16 come from our pre-study

Cactus Plot: Equivalent Cases



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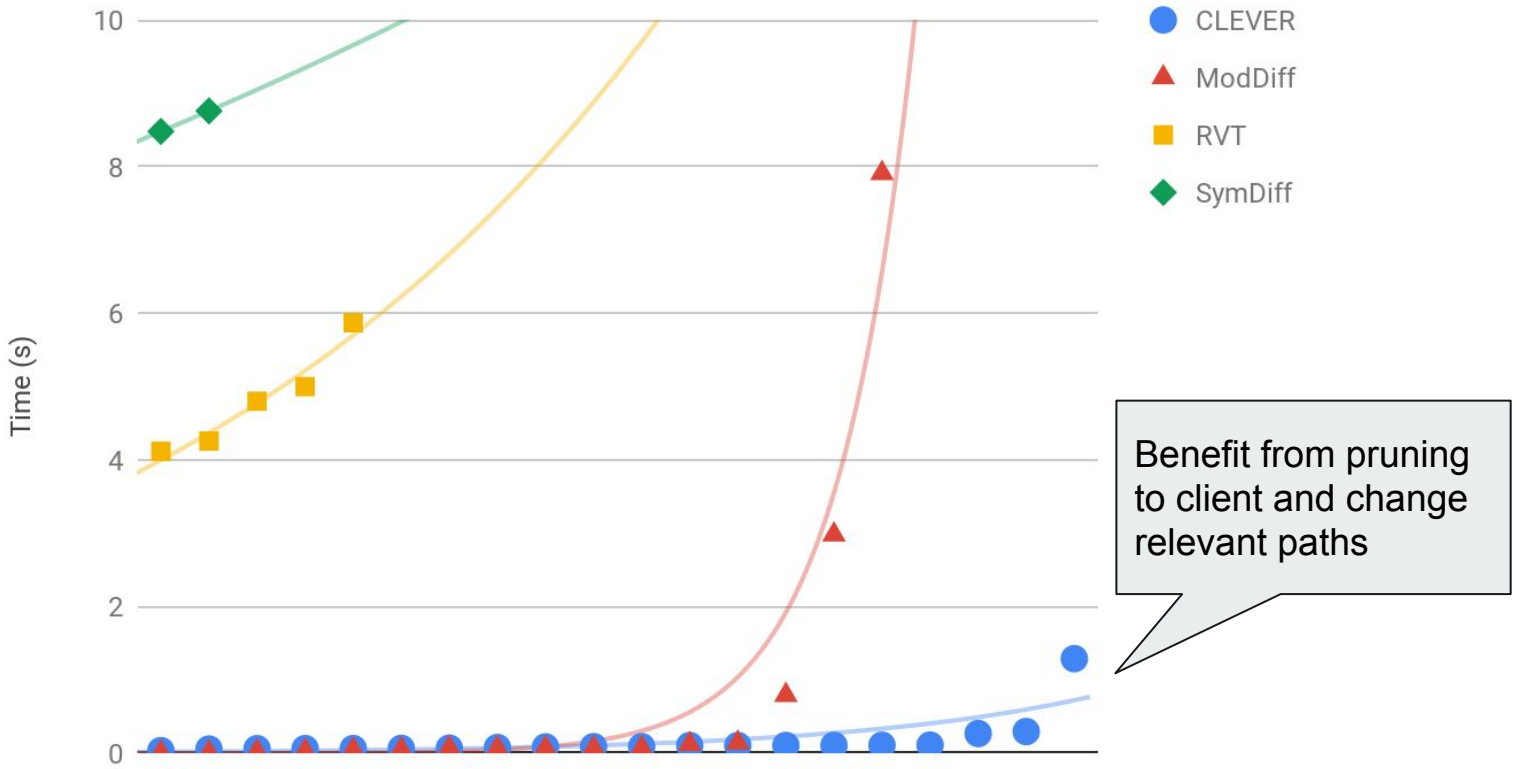
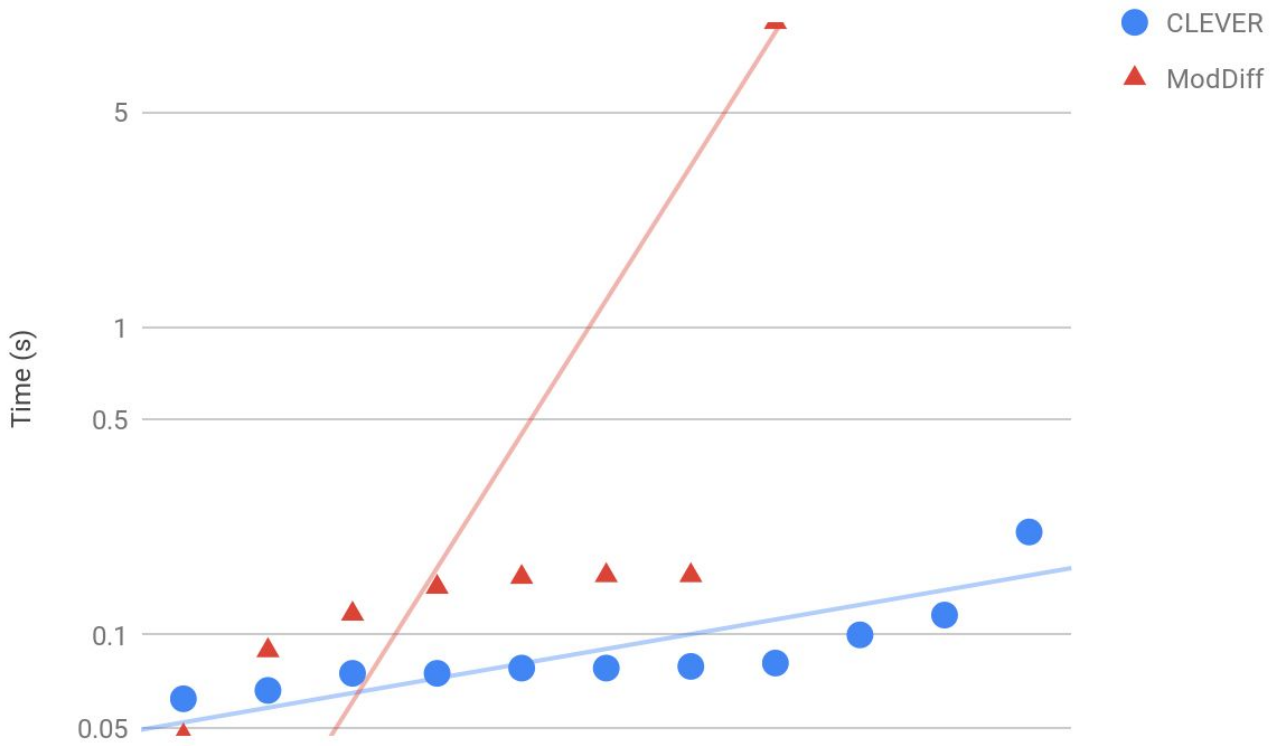


Cactus Plot (Log Scale): Non-Equivalent Cases



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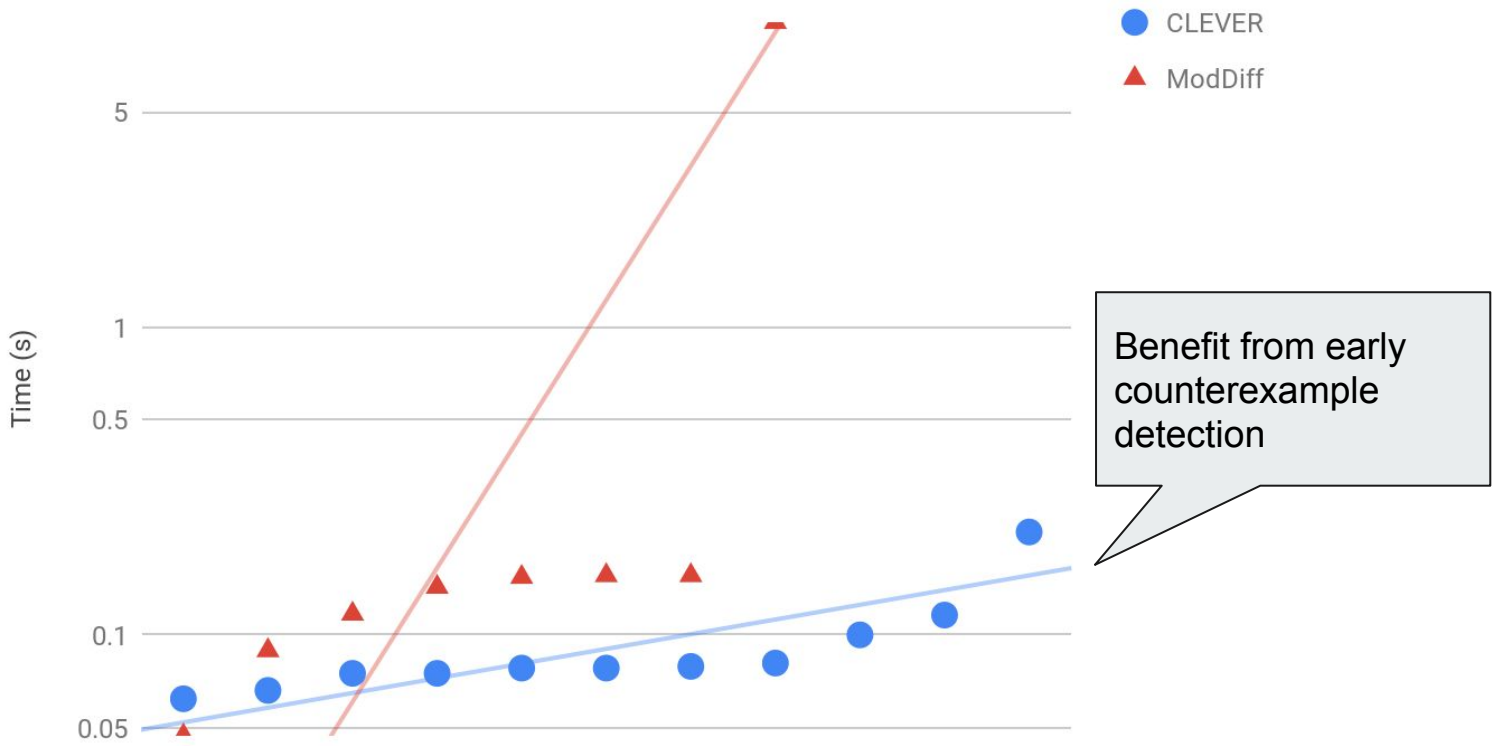


Conclusions & Beyond

Summary

- We identified client-specific equivalence checking
- Produced a technique and tool for checking it
  - Insight: existing techniques are too strong, or consider too much.
  - We consider only how the client uses the library and where the library change is active
  - We target patterns observed “in the wild”
- Evaluated our tool against the state-of-the-art
  - It does well!

Future Work

Lots of details are not considered, yet

- Go beyond functional equivalence
  - Total path equivalence: maintaining all intermediate executions of the client etc.
- Improvements on usability
  - Explain reasons for equivalence
  - Suggest changes/updates to clients

Benchmark size is still quite limited

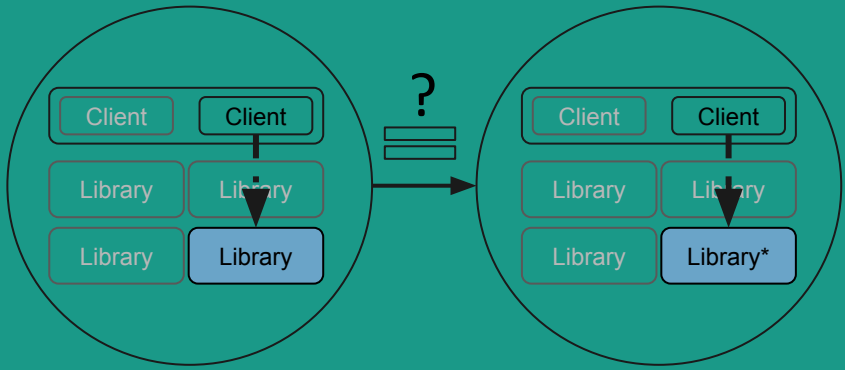
- Call backs, side effects, heap, etc.
- Increase support for primitive types
  - E.g. floating-point numbers, strings, and algebraic datatypes

Thank You!

CLEVER available at https://github.com/Client-Specific-Equivalence-Checker/CLEVER

Benchmarks and more available at https://client-specific-equivalence-checker.github.io/

PyExSMT available at https://github.com/FedericoAureliano/PyExSMT



Frequently Asked Questions

How Often Is a Client Unaffected by a Change/Does this problem exist in real life?

Applicability Study

Inspected 66 client-library function pairs

- Popular libraries on GitHub (>1,000 stars)
- Written in C and Python
- Went through 100 most recent commits which do not alter signatures
  - mostly bug fixes and
  - new behaviour introductions
- Searched for unique clients on GitHub

Applicability Study Results

Projects	Library Functions	# Client	# Affected	# Unaffected
OpenSSL	RN_is_prime_fasttest_ex	10	5	5
OpenSSL	RSA_check_key	32	5	27
Linux	gcd	11	8	3
GMP	mpf_get_d_2exp	7	1	6
Delorean	Delorean	3	0	3
Delorean	Delorean2	3	0	3
All	All	66	19	47

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All	All	66	19	47

- ~71% of the clients are unaffected!

How does CLEVER scale with increasing number of paths?

(Since our approach is based on path exploration)

CLEVER Vs. ModDiff by Number of Paths

Experiment: Take ModDiff equivalent benchmarks, keep structure, but increase number of paths

Non-Equivalent Cases even more stark.