Playing with process tracing to instrument static function at runtime in EZTrace

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INTRODUCTION

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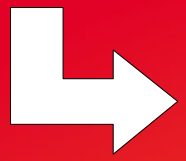

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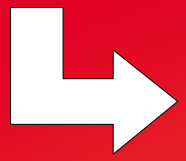

PROCESS TRACING

OUTLINE

1. EZTrace insights
2. The ptrace() system call
3. Instrumentation of static functions in EZTrace
4. Technical details for the geek
5. Other architectures...

1
EZTrace Insights

EZTrace basics

EZTrace is a trace generator:

```
$ export EZTRACE_TRACE="mpi pthread"
$ mpirun -np 16 `eztrace -e mpiapp`   or   $ eztrace pthreadapp
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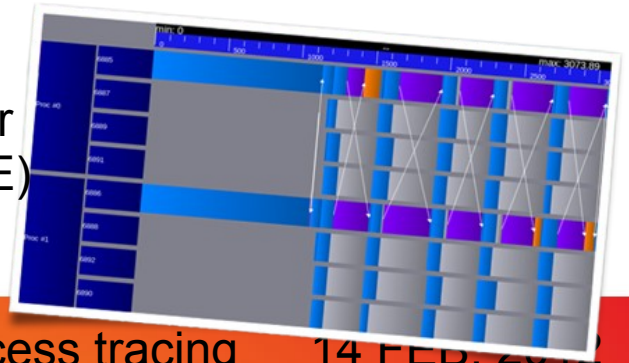
Visualizer
(ex.: ViTE)



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ON DYNAMIC LIBRARIES!

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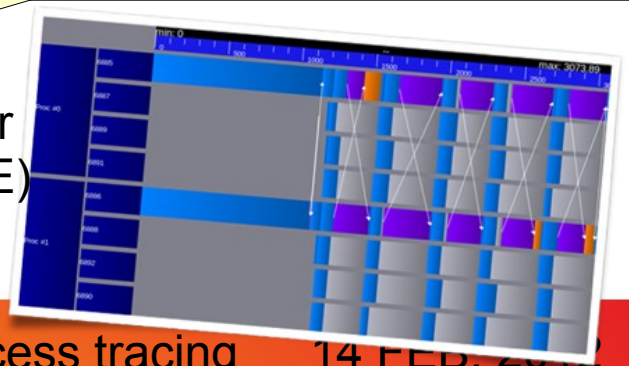

EZTrace is good for your health

You can use EZTrace to trace parallel programs in order to:

- Detect problems in message exchanges and in parallel algorithm
- Improve communication patterns
- Show beautiful traces of your software to the world

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- Trace non-parallel programs
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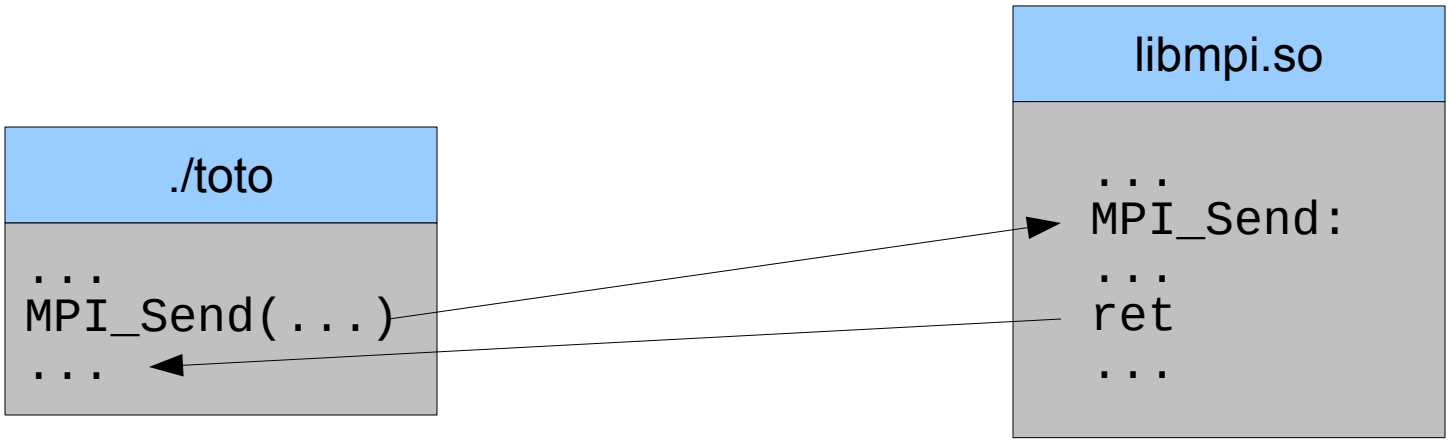
You cannot (currently) use EZTrace to:

- Stop when a memory error occurs
- Trace your own library or non-packaged library
- Trace static libraries
- Make the coffee

Dynamic library loading



Dynamic library preloading
With an EZTrace module

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LD_PRELOAD=”libeztrace_mpi.so”
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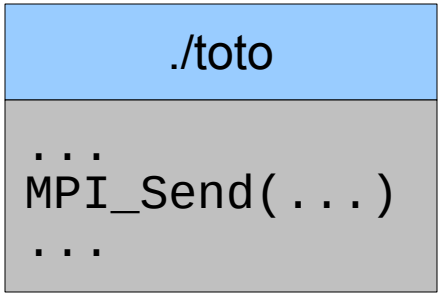

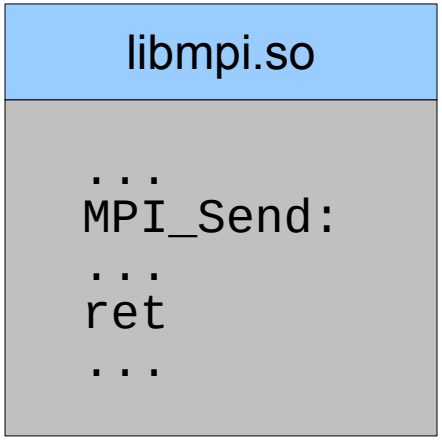

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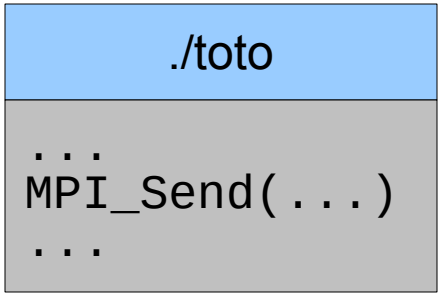

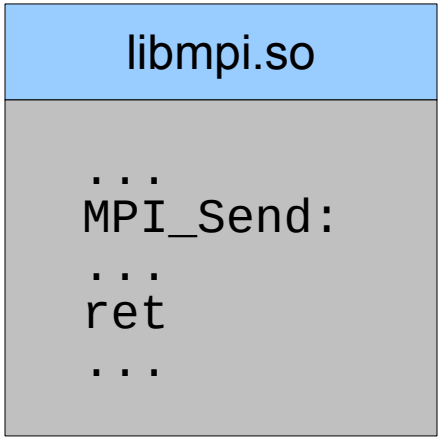

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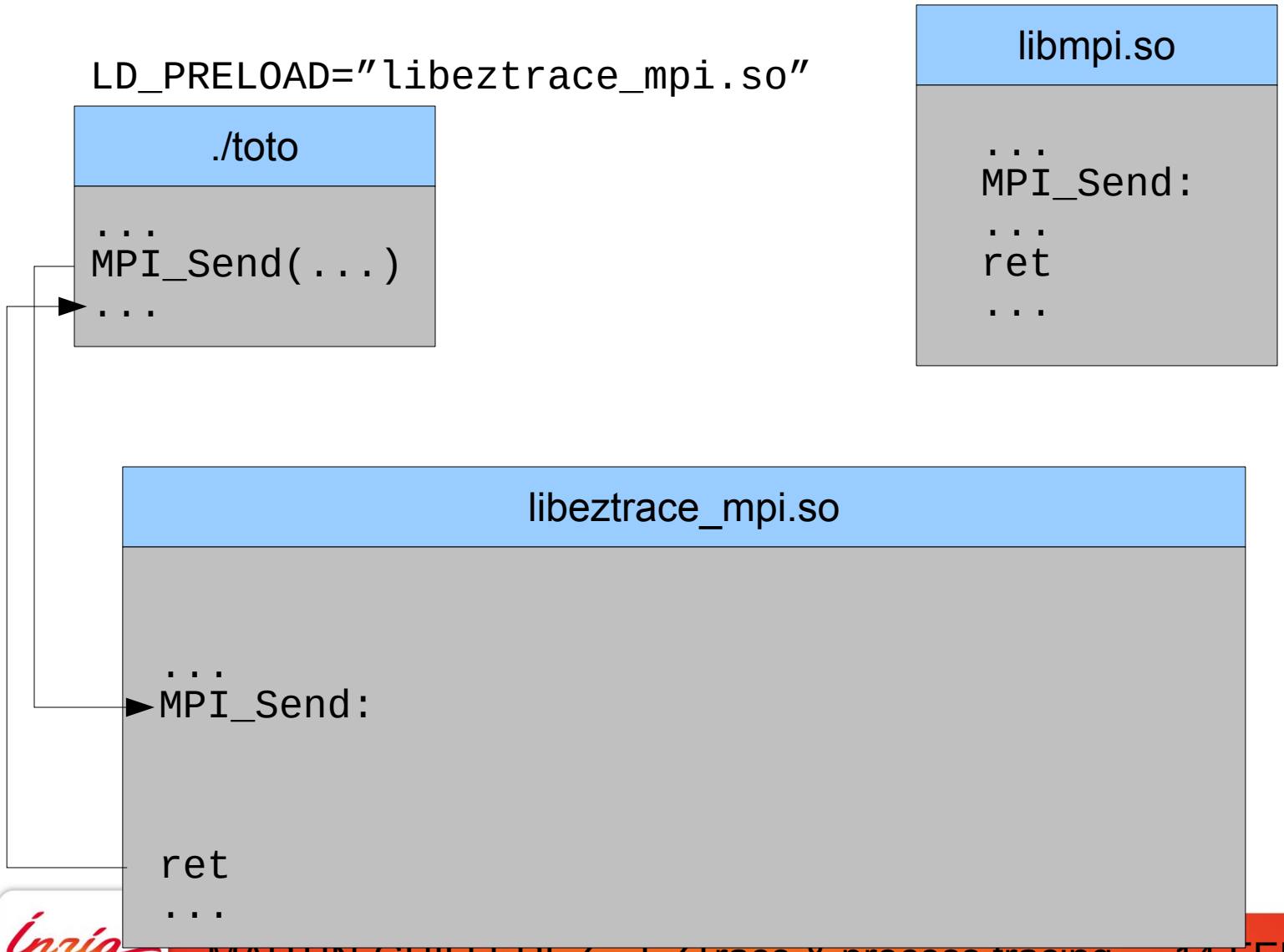

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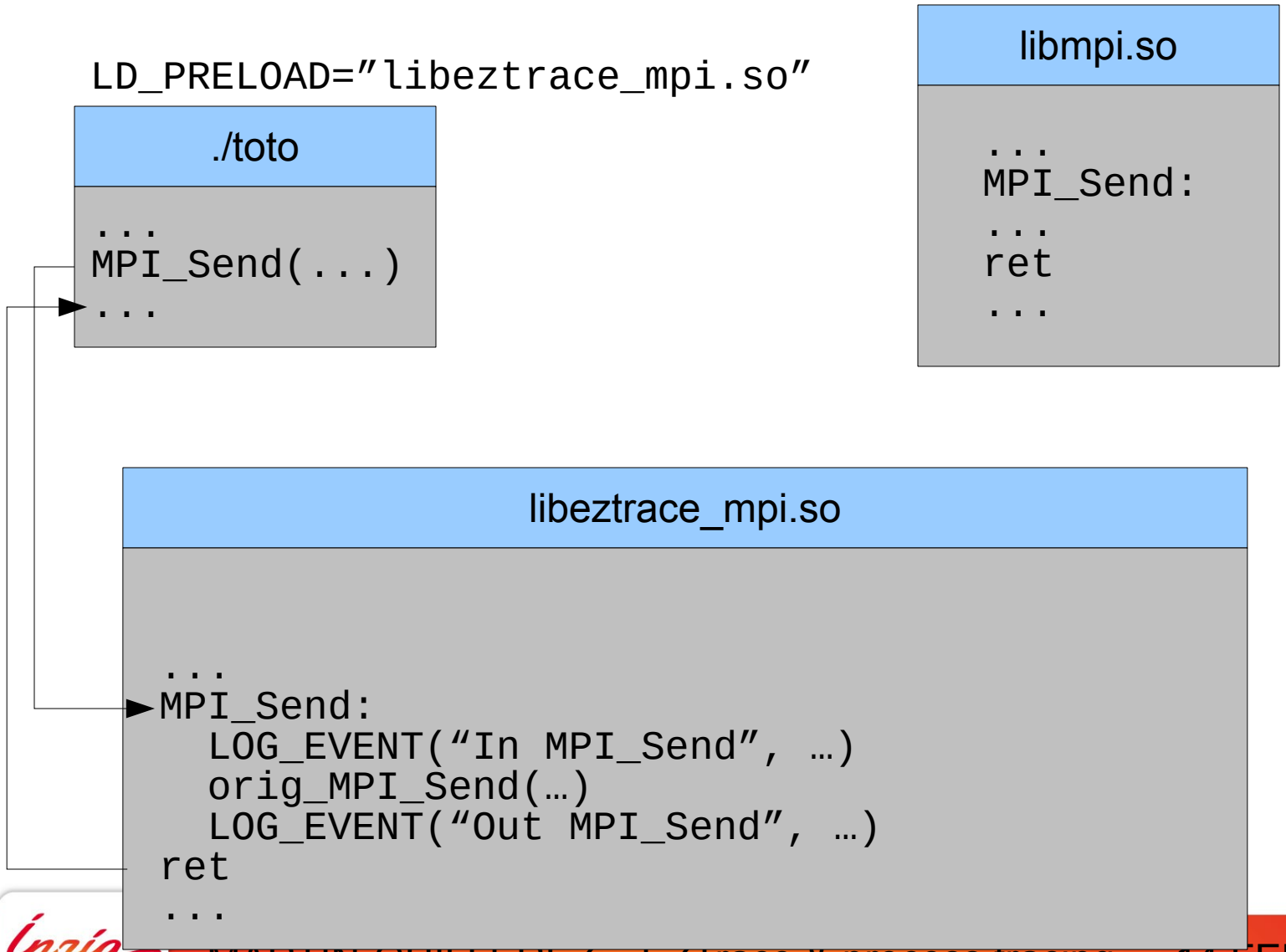

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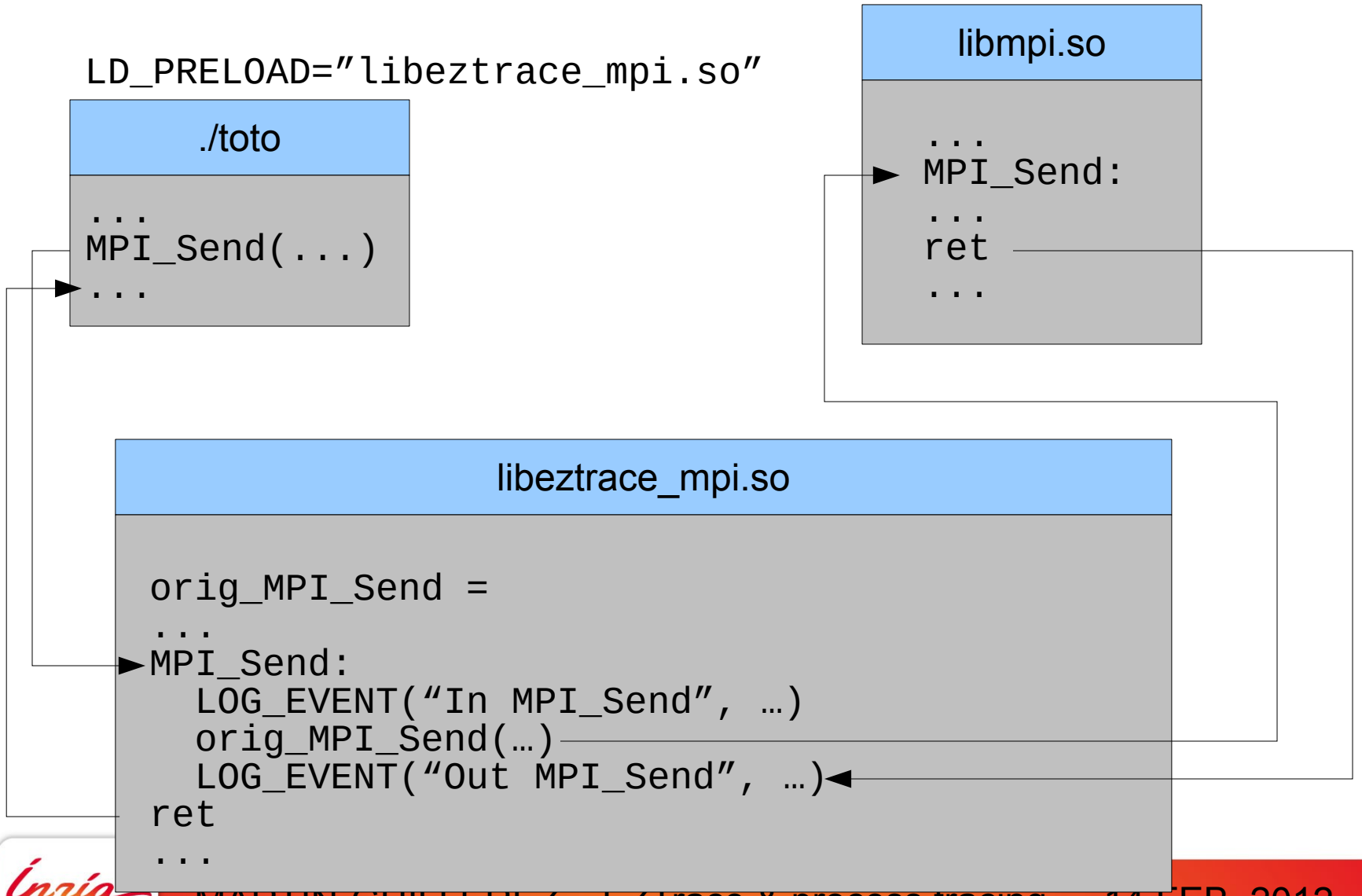

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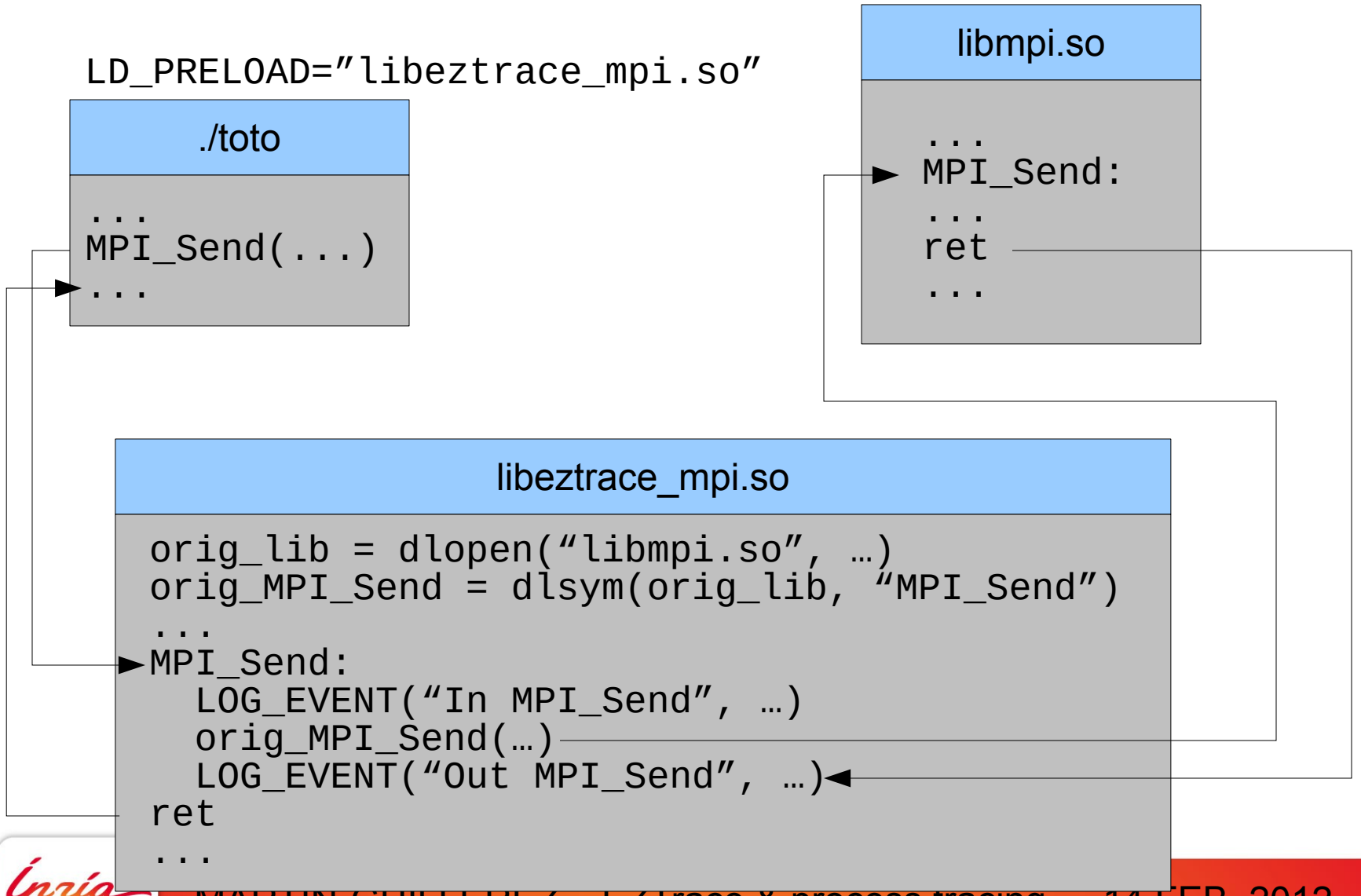

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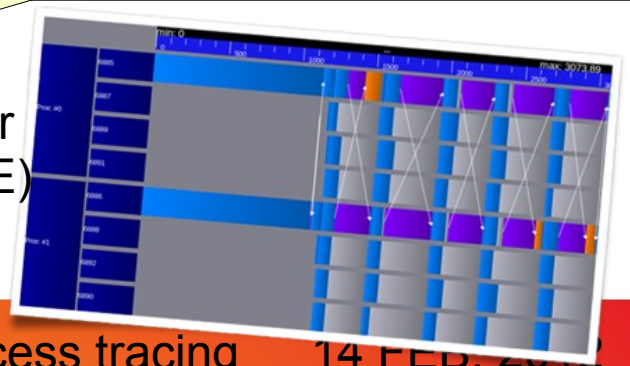

It is the story of a fool that says to another fool who says to another fool that...

2

The ptrace() system call

ptrace() stands for process tracing

ptrace() is:

- A POSIX system call
- Extended in its Linux version
- A process tracing mechanism
  - Attach and detach a target process
  - Stop at each system call / each instruction of target process
  - Examine and modify target memory and registers

```
#include <sys/ptrace.h>

int ptrace(int requête, int pid, void* addr, void* data);
```

man 2 ptrace

ptrace() process attachment

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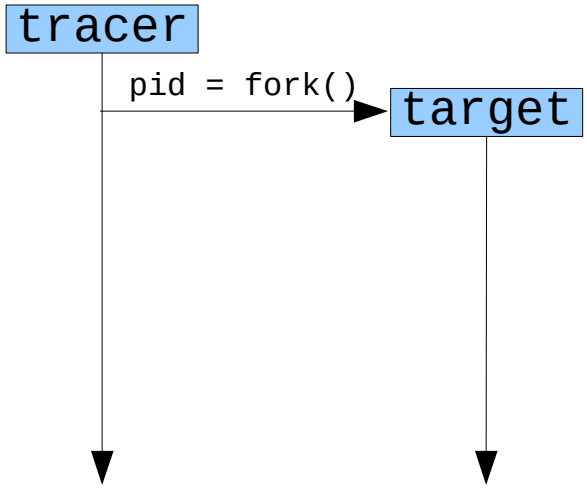

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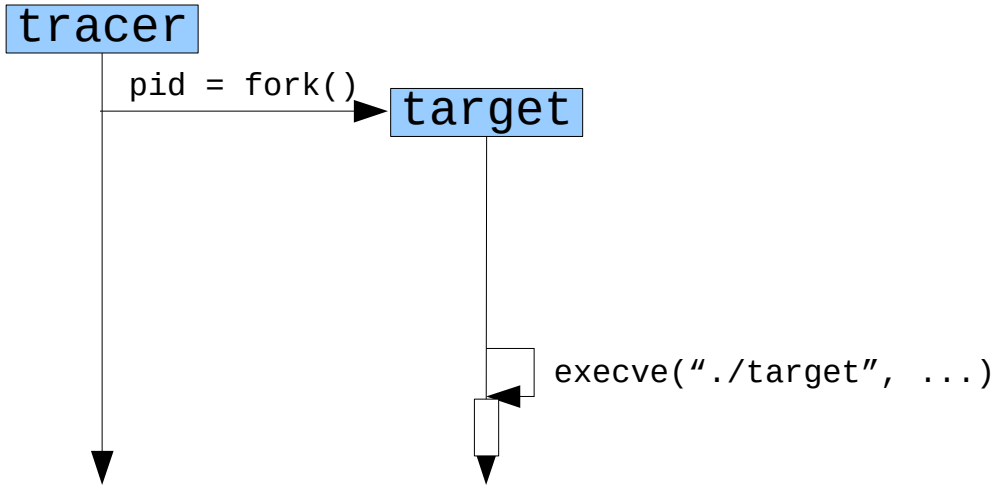

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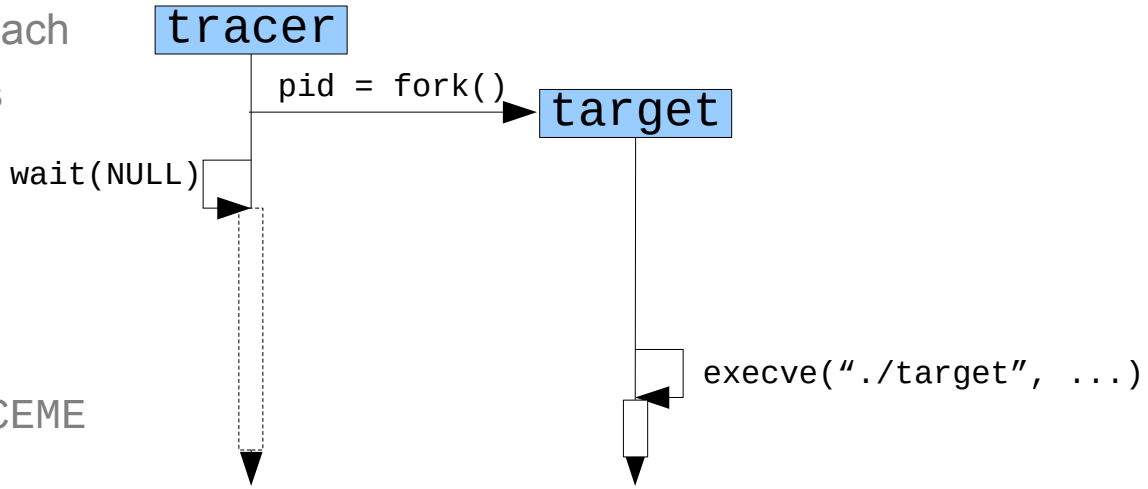

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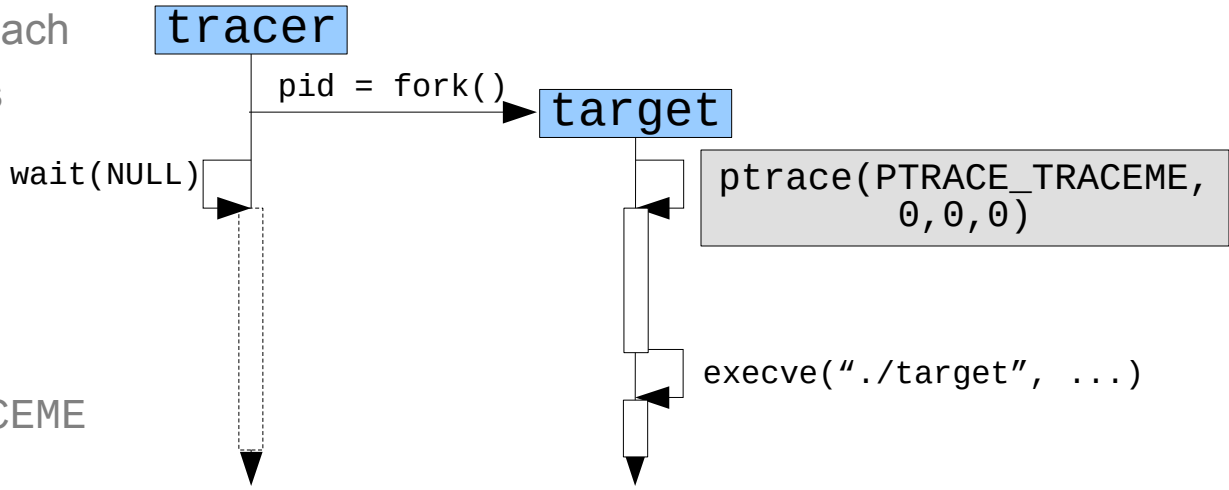

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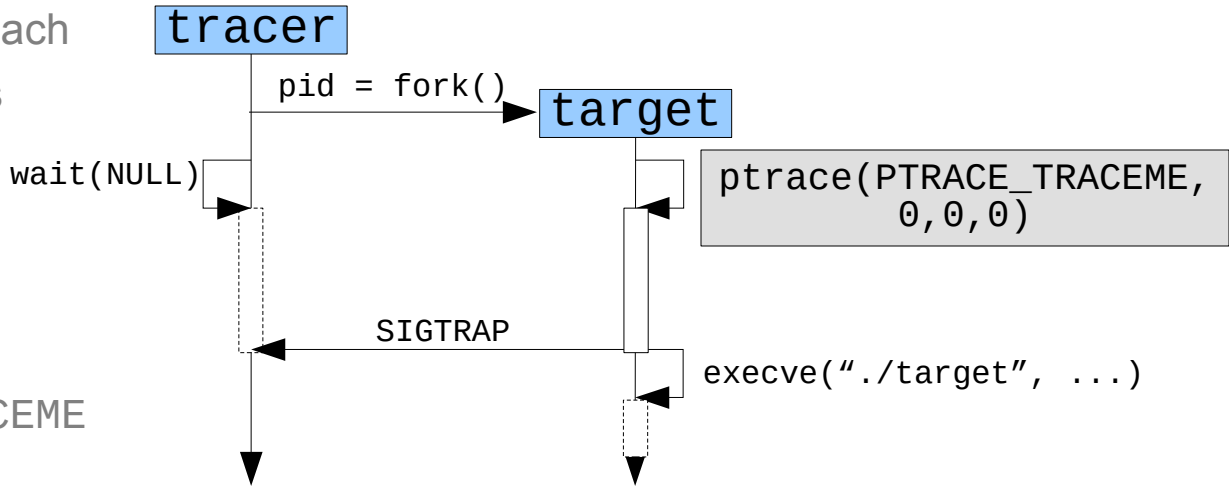

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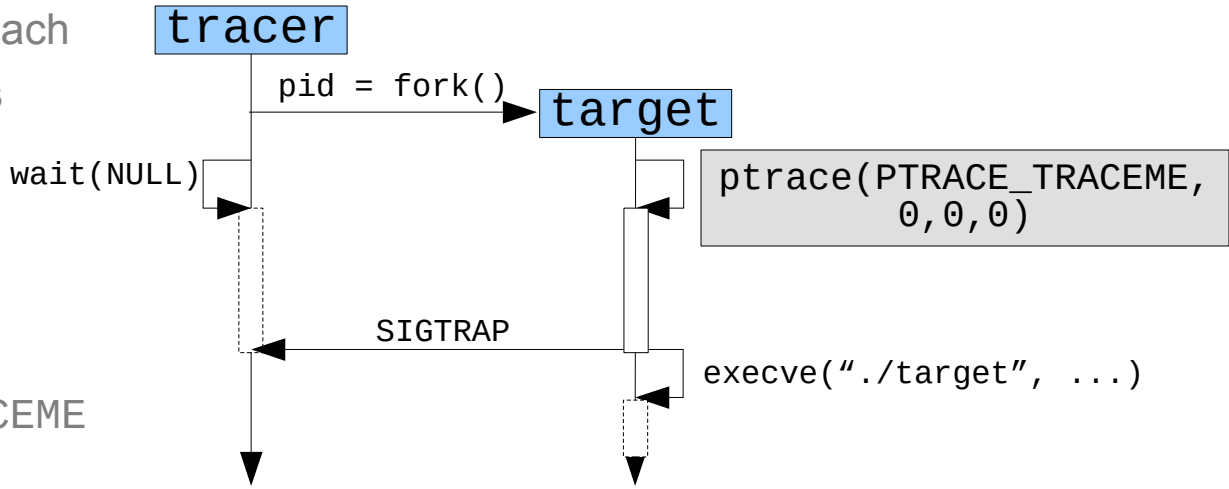

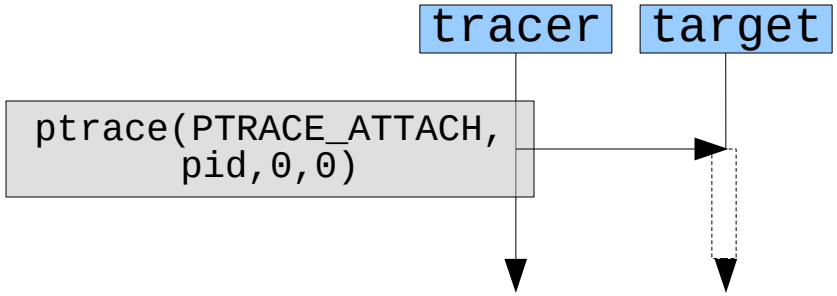

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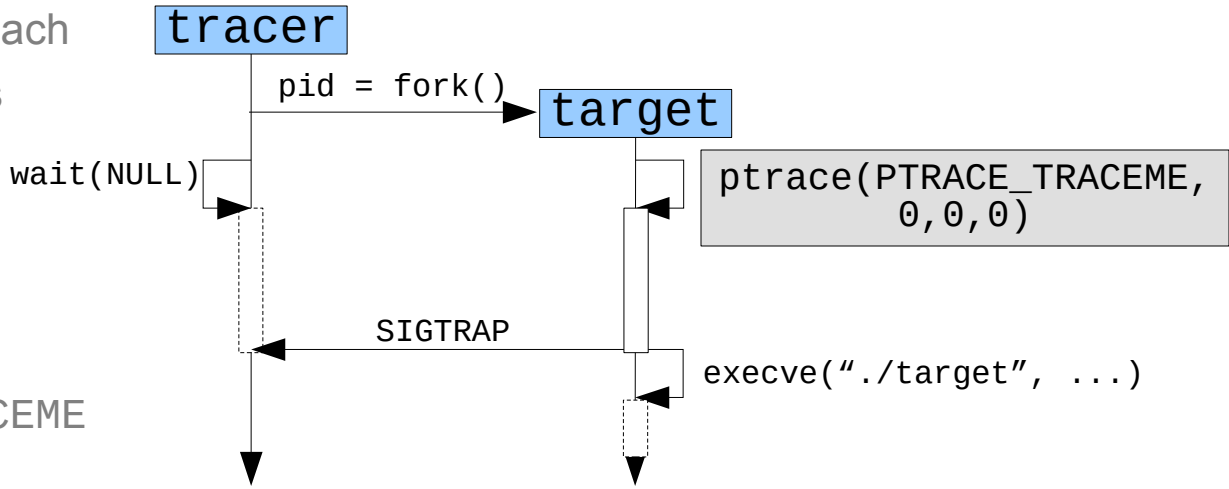
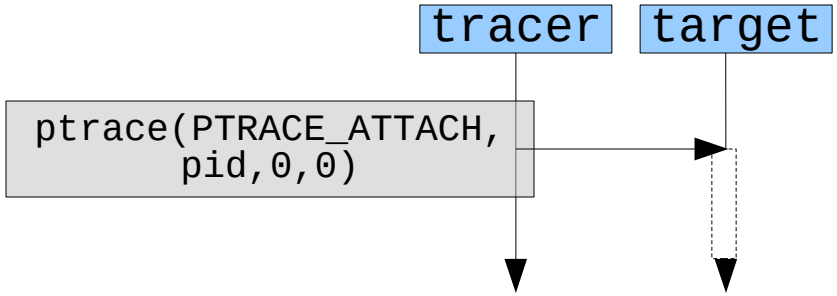
- Detaching using `PTRACE_DETACH`





ptrace() stepping

- Continue until next signal

```
ptrace(PTRACE_CONT, pid, NULL, NULL);
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ptrace(PTRACE_CONT, pid, NULL, NULL);
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- Continue until next system call
  - Stops at system call entry and exit

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ptrace(PTRACE_SYSCALL, pid, NULL, NULL);
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ptrace(PTRACE_SYSCALL, pid, NULL, NULL);
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- Stop after next instruction

```
ptrace(PTRACE_SINGLESTEP, pid, NULL, NULL);
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```

ptrace() memory reading and altering

- Reading / writing target memory

```
type_of_word data;
data = ptrace(PTRACE_PEEKTEXT, pid, (void*)addr, NULL);
ptrace(PTRACE_POKETEXT, pid, (void*)addr, (void*)data);
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- Reading / writing target registers

```
#include <sys/user.h>
struct user_regs_struct regs;
ptrace(PTRACE_GETREGS, pid, NULL, (void*)(&regs));
ptrace(PTRACE_SETREGS, pid, NULL, (void*)(&regs));
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- Reading / writing target user data

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#include <sys/user.h>
struct user u;
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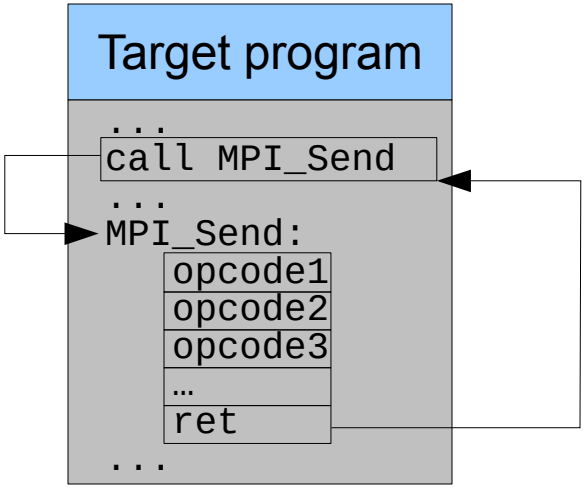
- Reading target signal informations

```
siginfo_t siginfo;
data = ptrace(PTRACE_GETSIGINFO, pid, NULL, (void*)(&siginfo));
```

3

Instrumentation of static functions in EZTrace

How to instrument static functions ?



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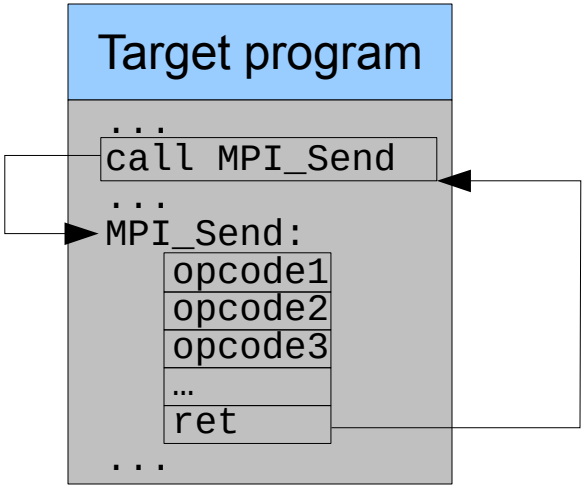

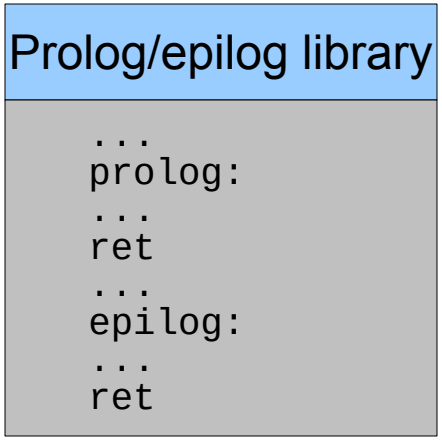

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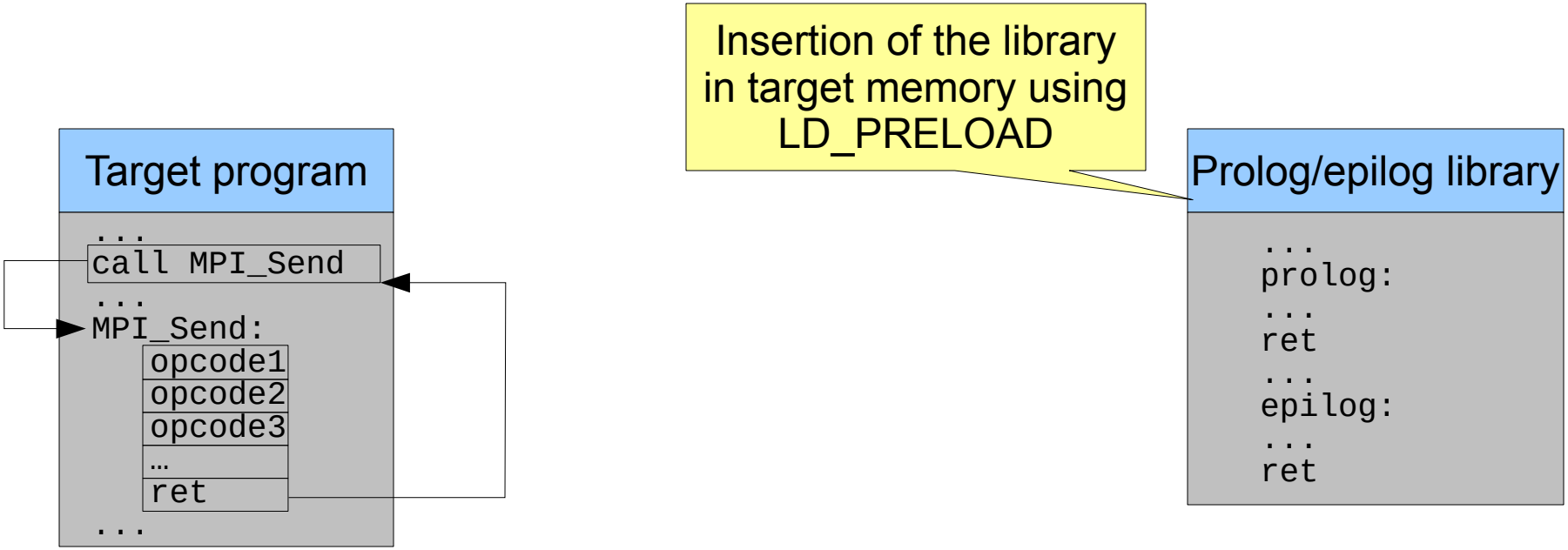

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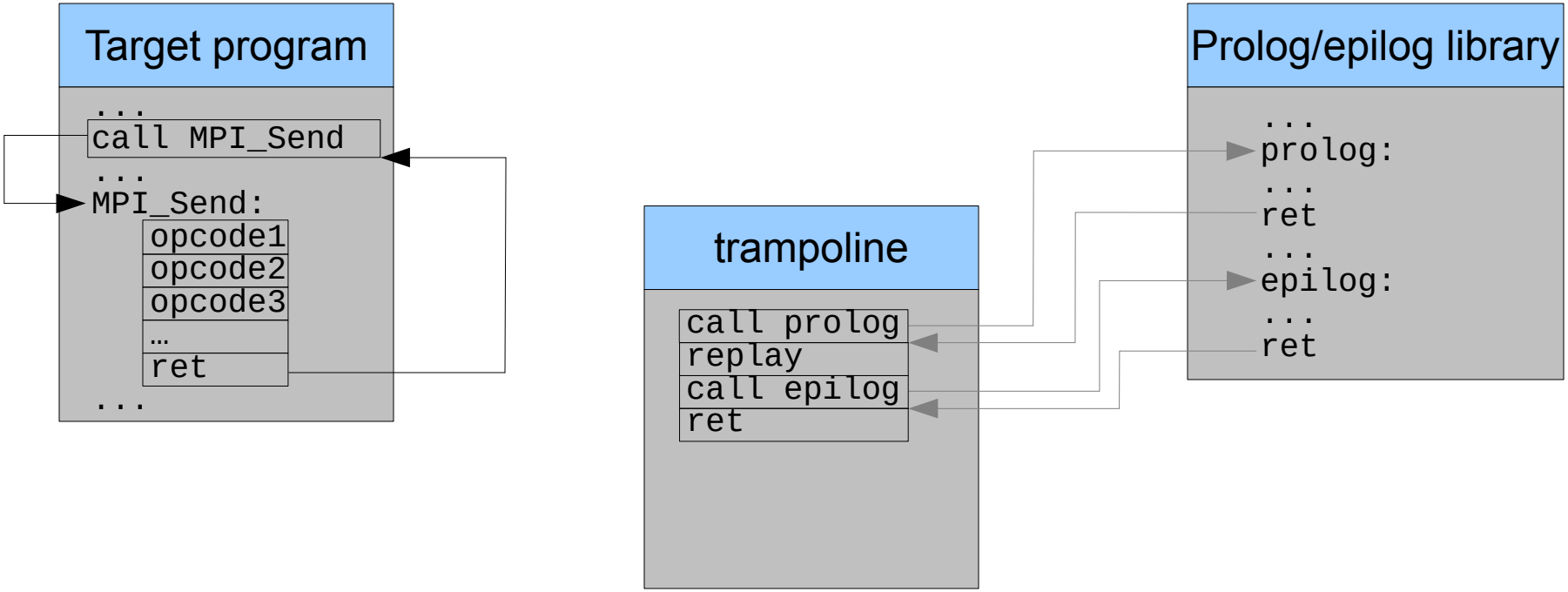

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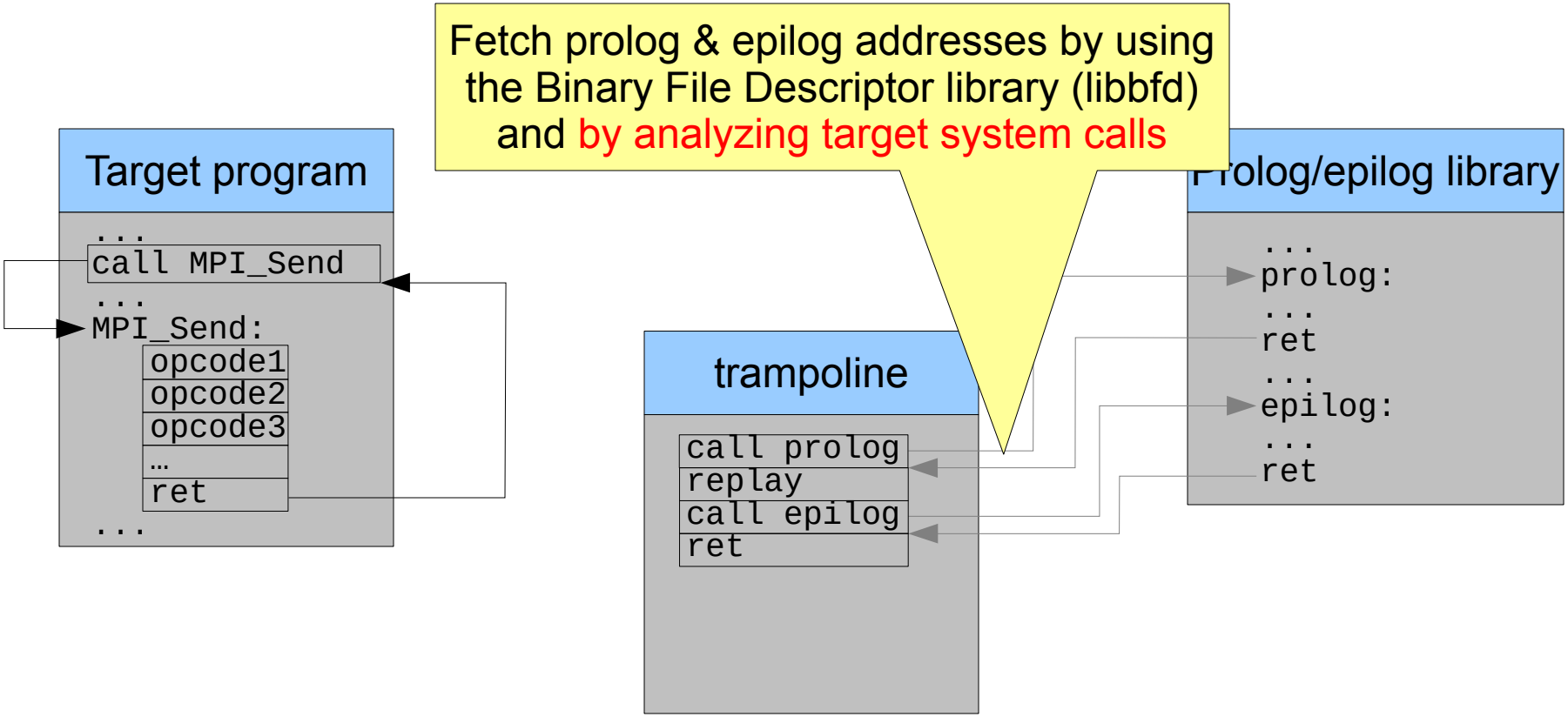

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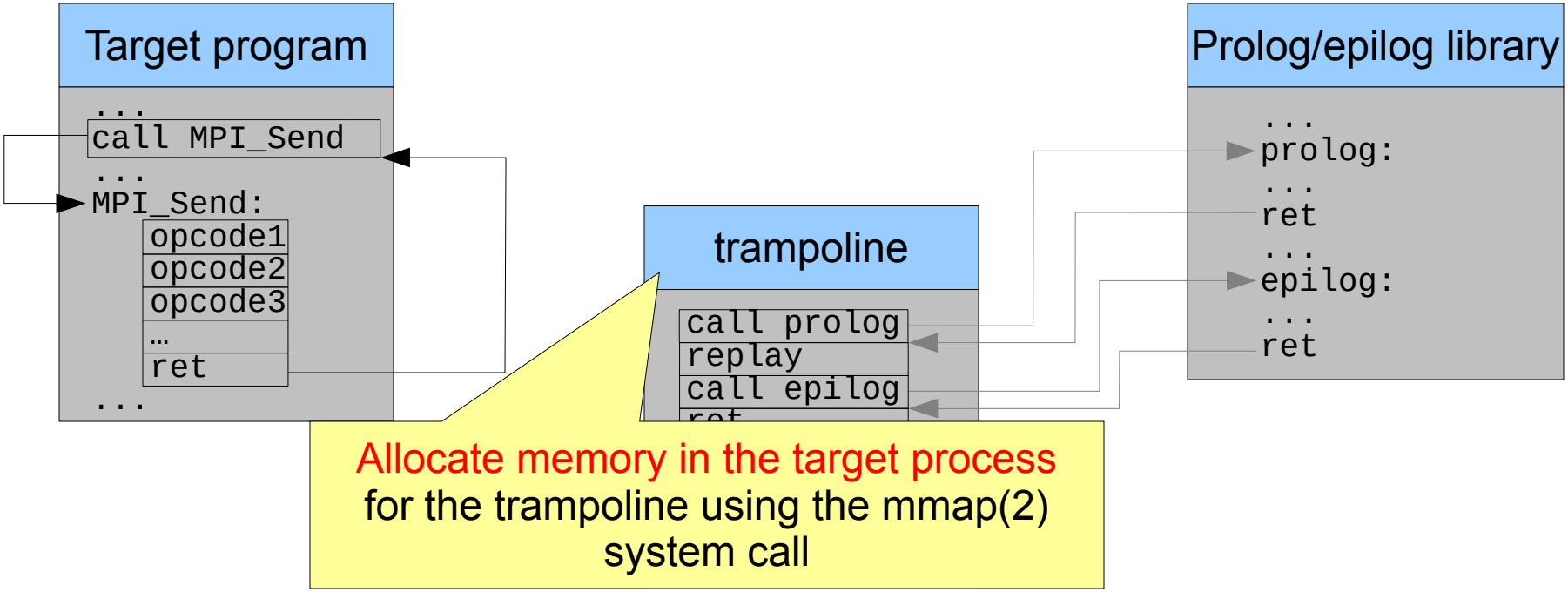

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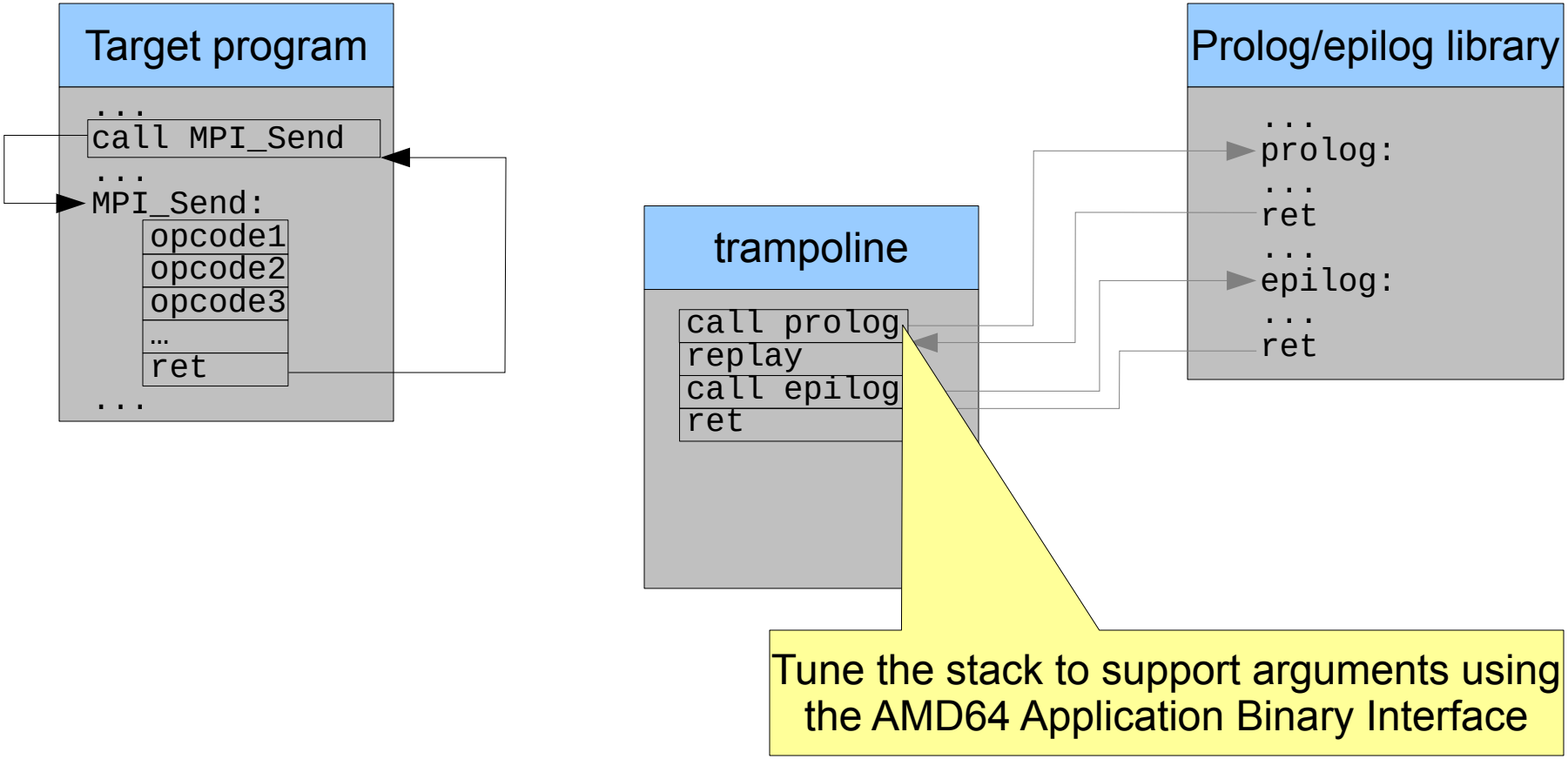

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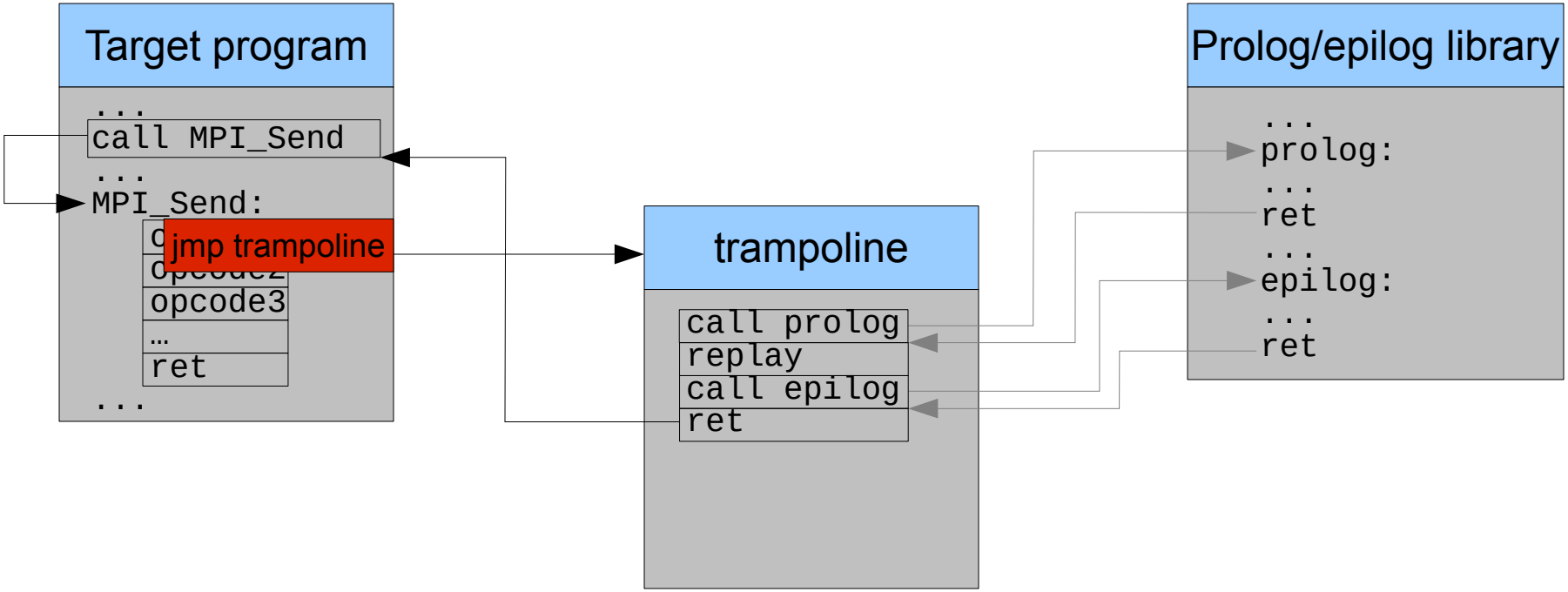

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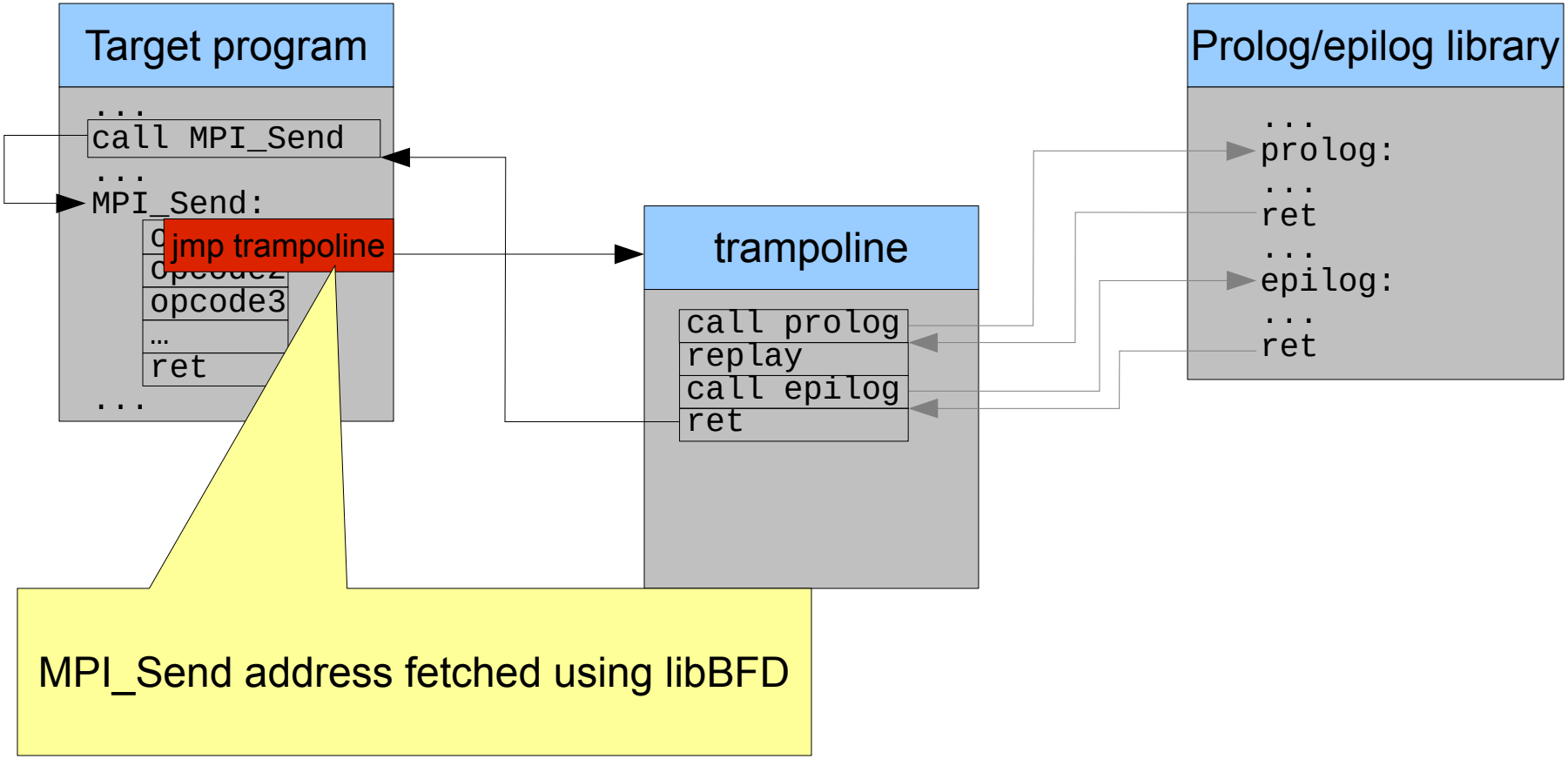

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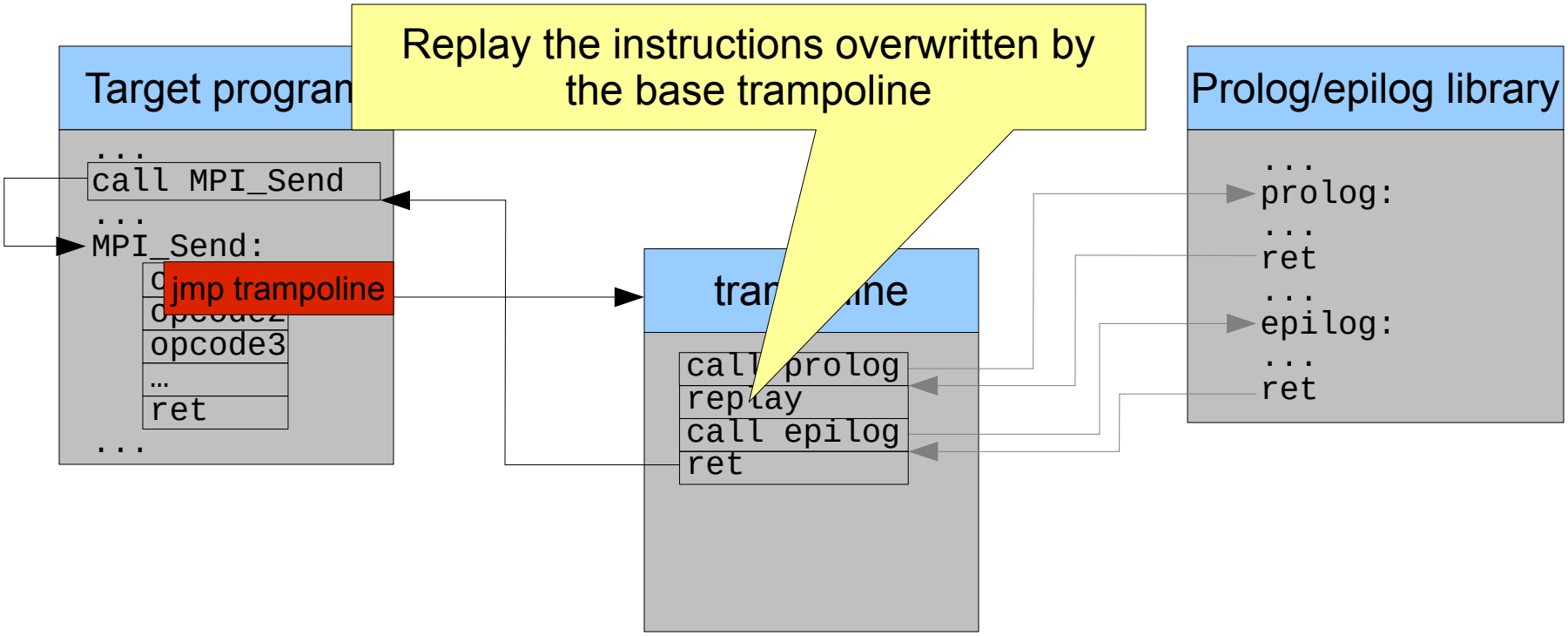

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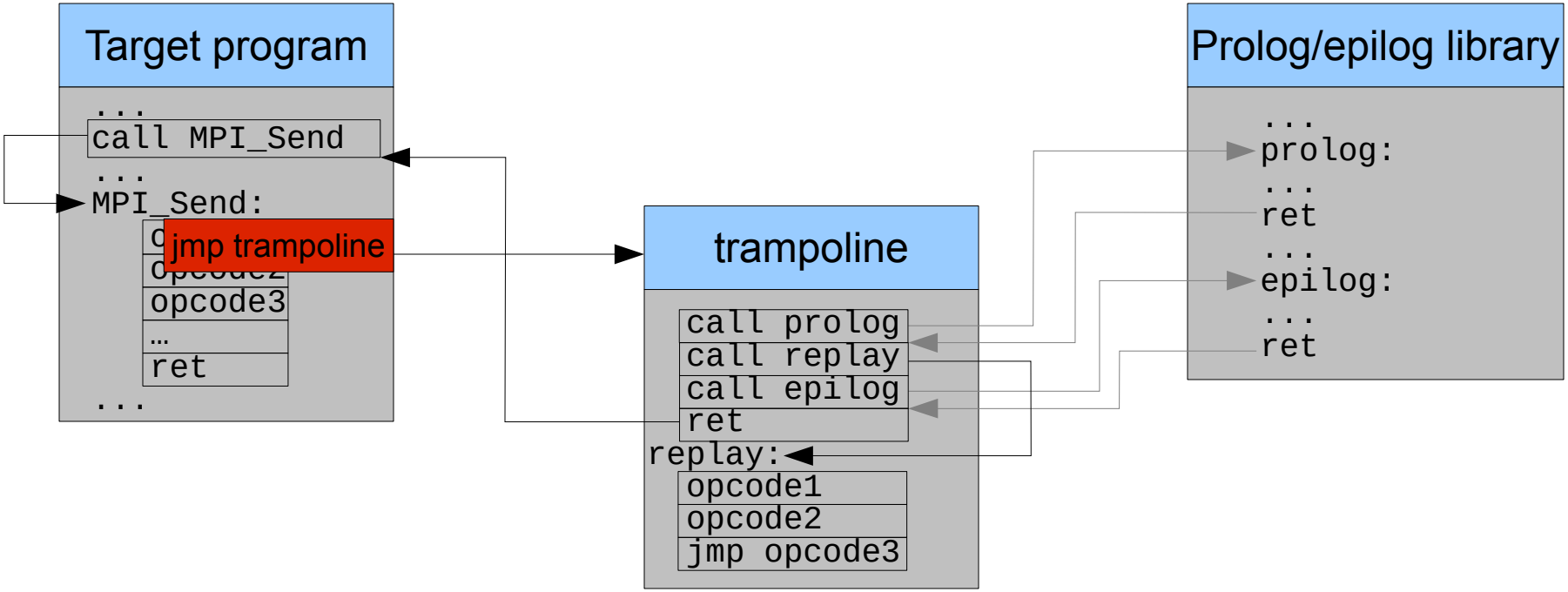

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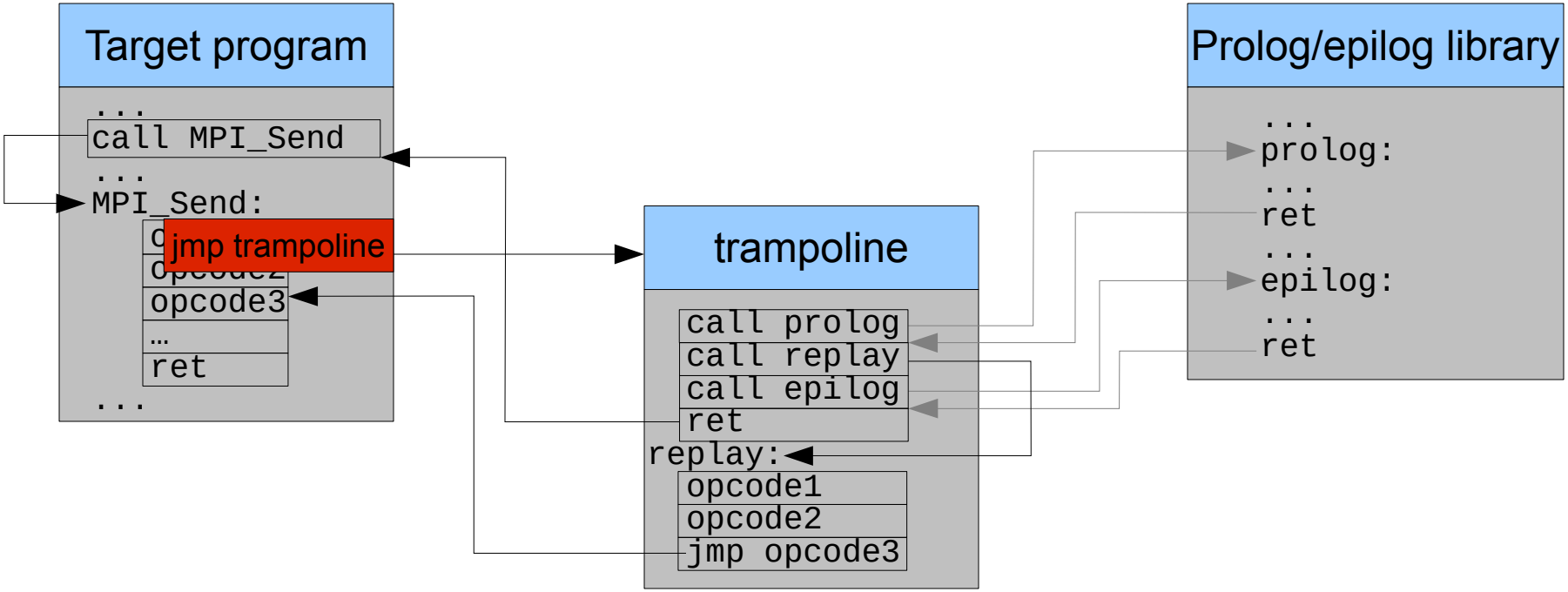

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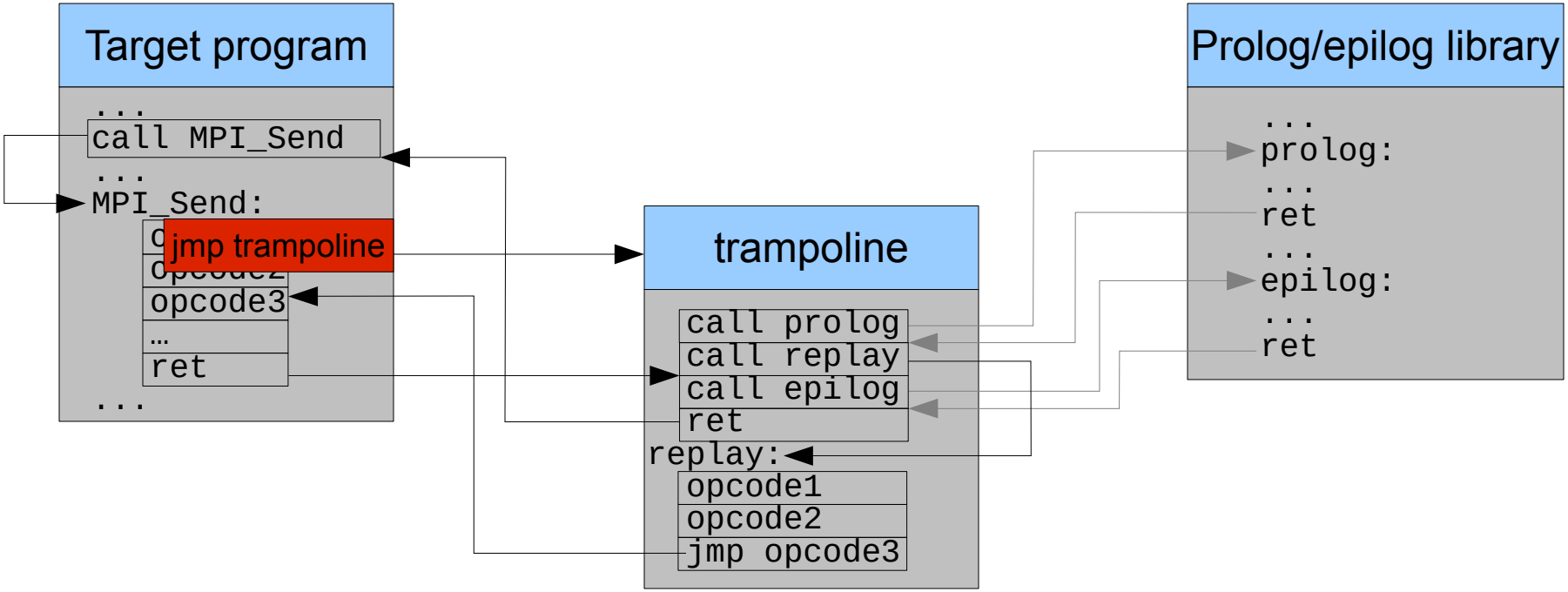

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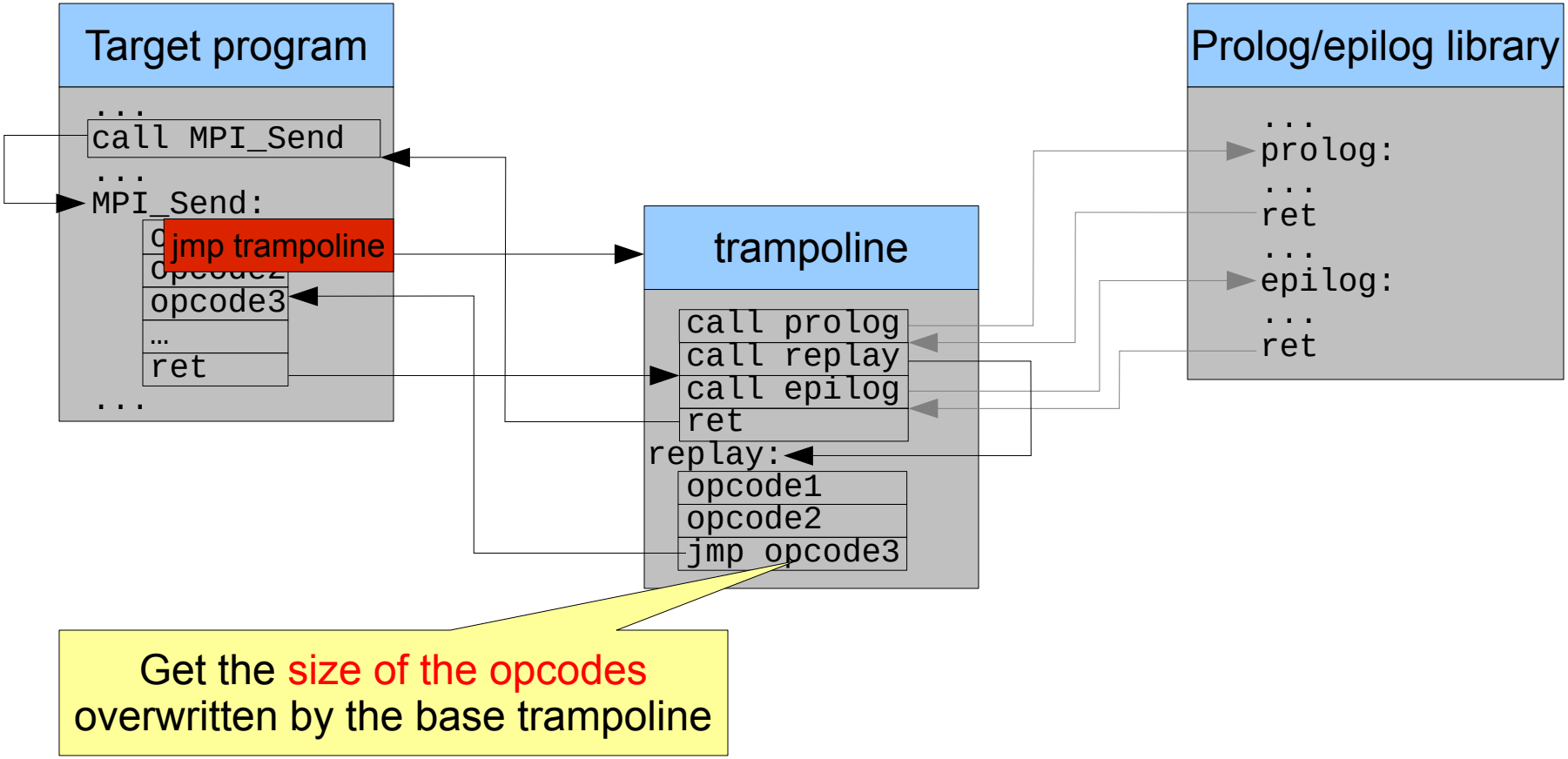

4

Technical details for the geek

Technical challenges left

- Allocate memory in the target process
- Get the address of the preloaded library
  - The offset of the prolog and epilog inside the library are fetched with libbfd
  - The library loading mechanisms is spyed to find the mmaping of the library
- Get the size of the overwritten opcodes

The mmap() system call

The mmap() system call allocate a memory page

```
#include <sys/mman.h>

void* mmap(void *addr, size_t len, int prot,
                       int flags, int fd, off_t offset)
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man 2 mmap

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man 2 mmap

- Can be used to map a library in memory
- Can also be used to allocate an executable segment for the trampoline

Calling a system call from the parent process

To call `mmap()` to allocate memory for the trampoline, we need to:

- Stop the target process
- Replace the current instruction by an `int 0x80 (syscall)`
- Set the accumulator (`rax`) to the system call number
- Fill the other registers according to the ABI
- Executes two `ptrace(PTRACE_SYSCALL, pid, NULL, NULL)`
- Get the result from the registers
- Restores the registers and the current instruction

Fetching the library base address

The base address of a preloaded library is determined at runtime.

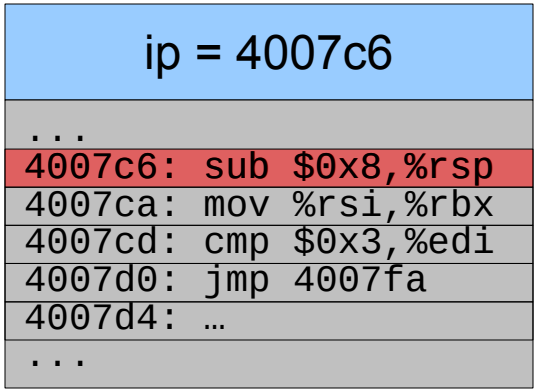
- The dlopen() mechanism do it by:
  - Opening the library file using the open() system call
  - Mapping it in memory using the mmap() system call

- Thus to fetch the base address:
  - Wait for `open(«library.so», *) = fd`
  - Wait for `mmap(*, *, *, *, fd, *) = baseAddress`

- A wait is performed using the `PTRACE_SYSCALL` method and by looking into registers

Getting the overwritten opcode size

Obtained by single stepping...



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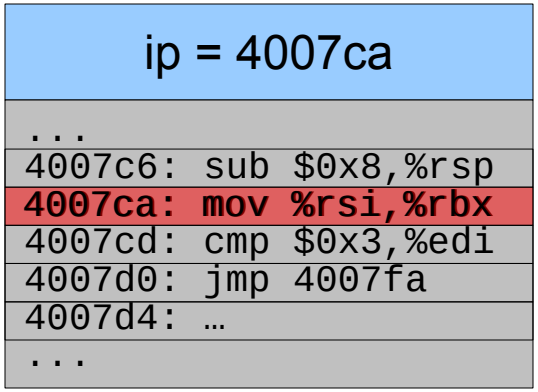

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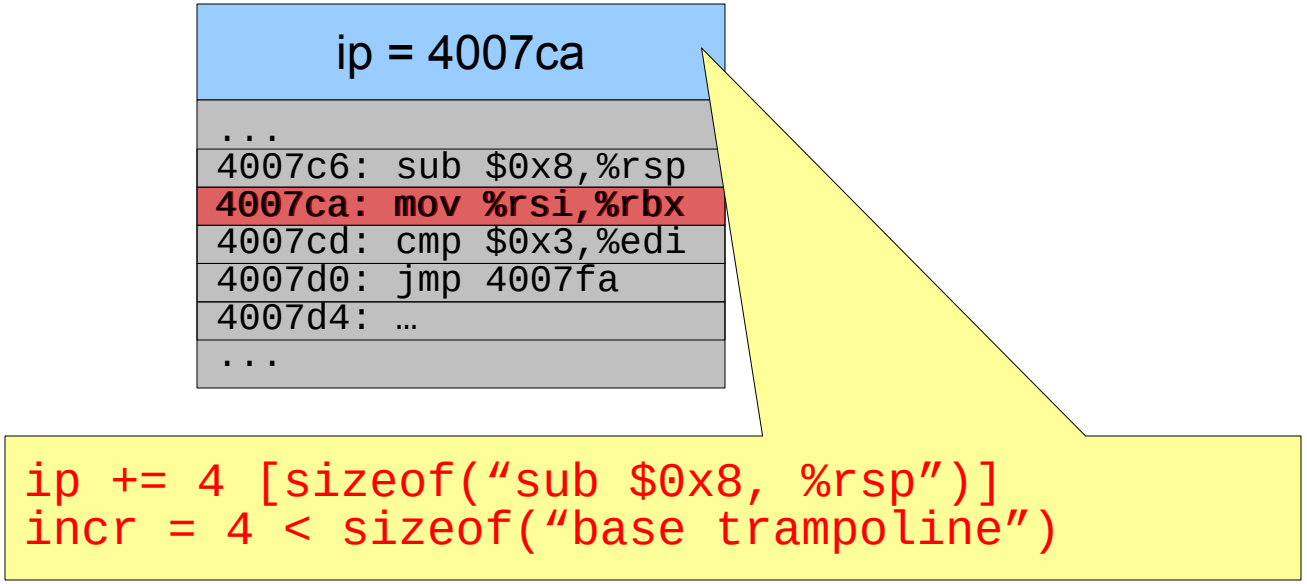

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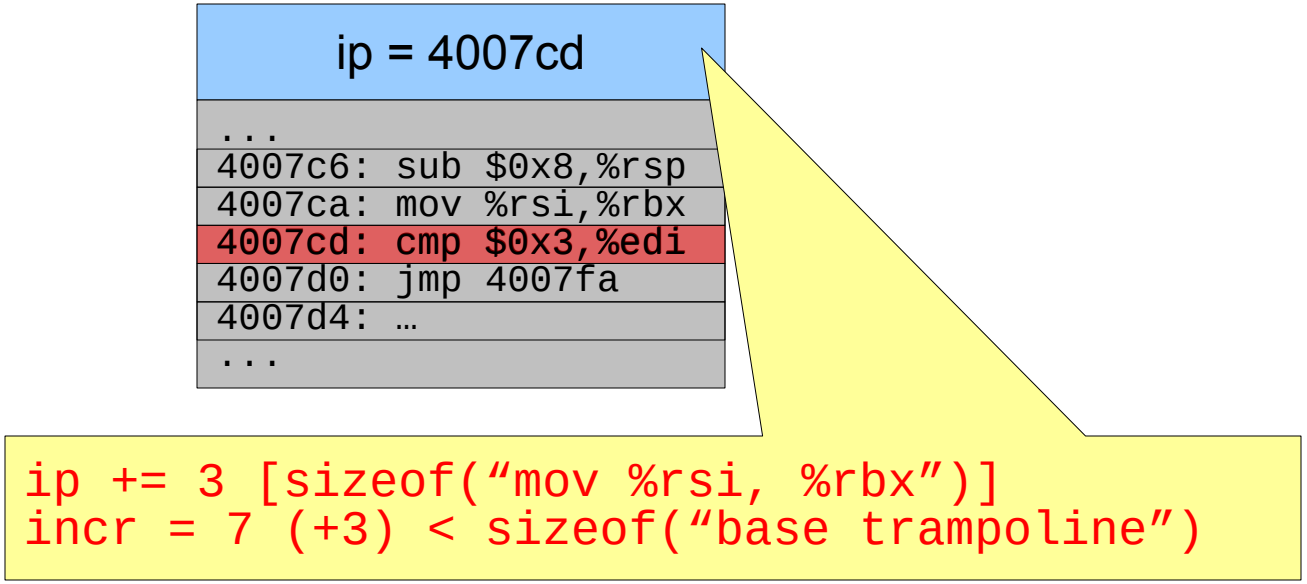

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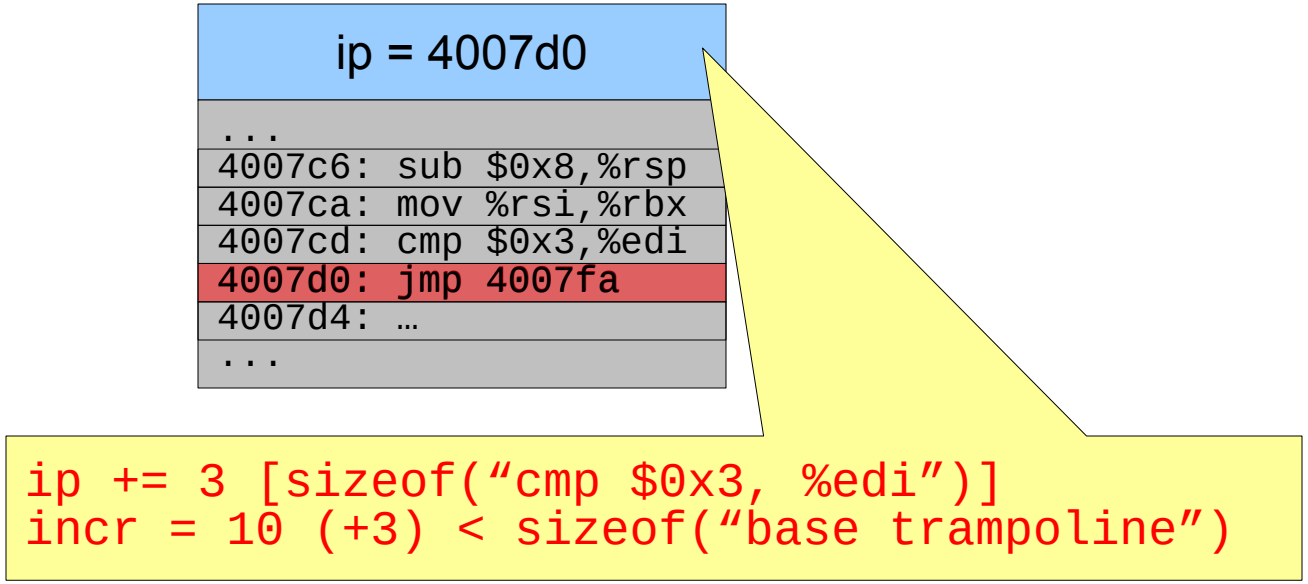

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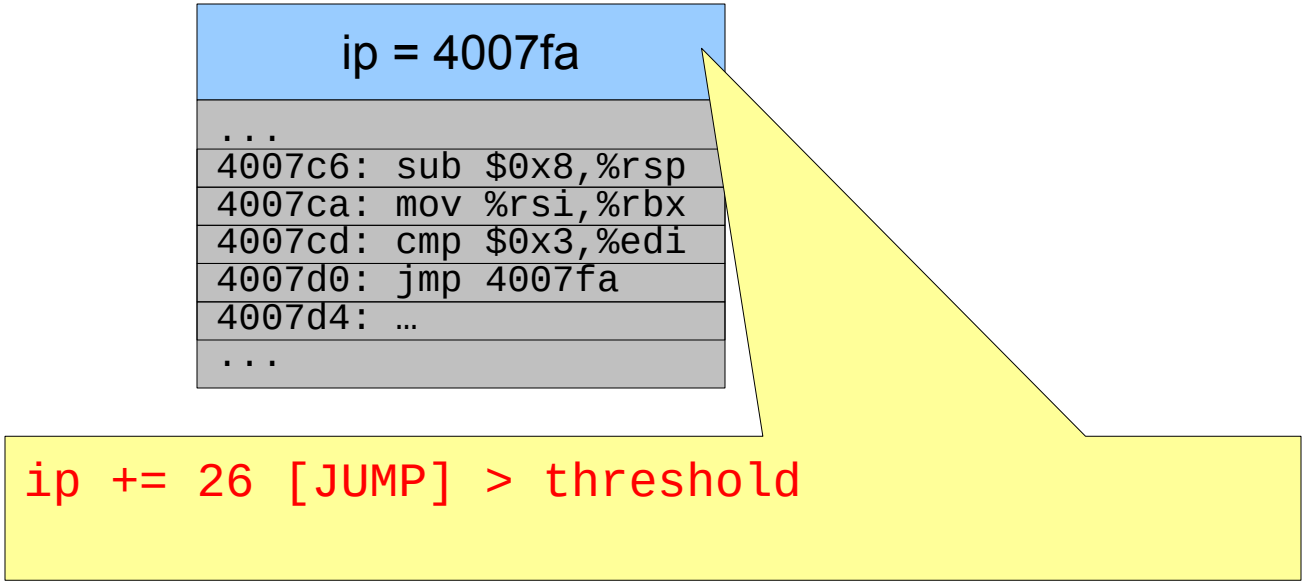

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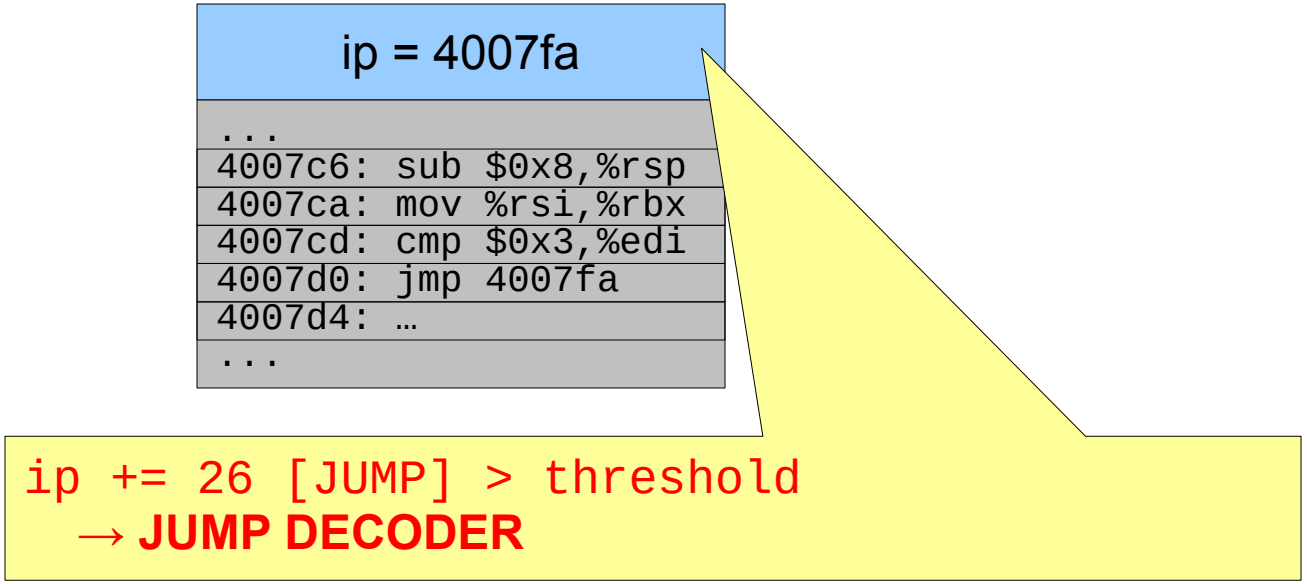

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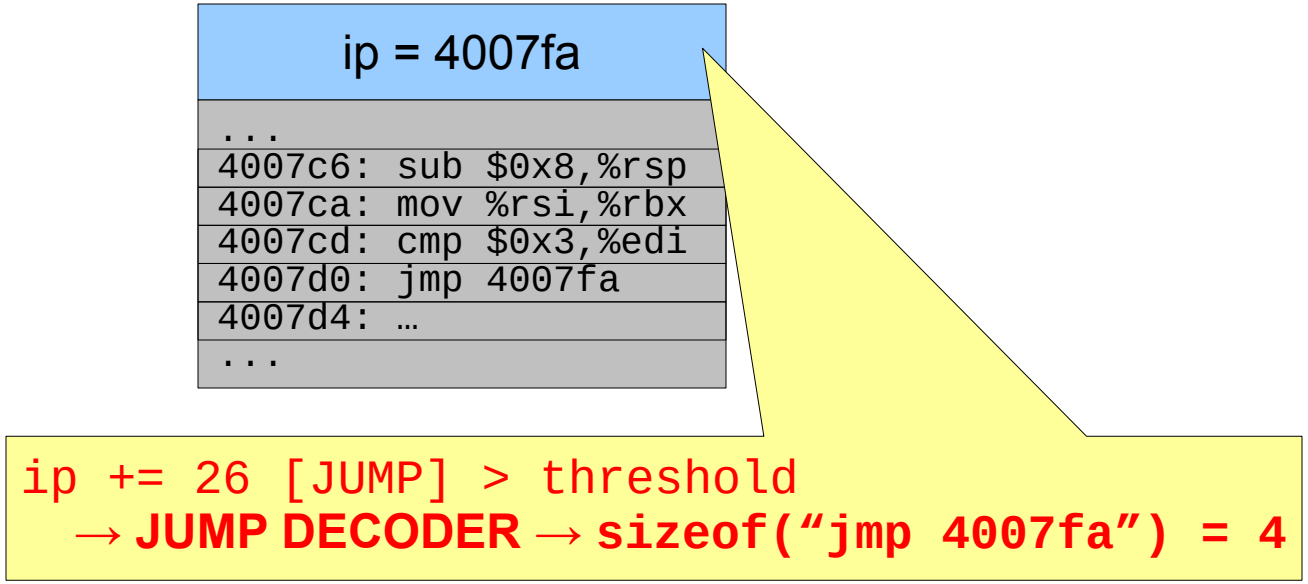

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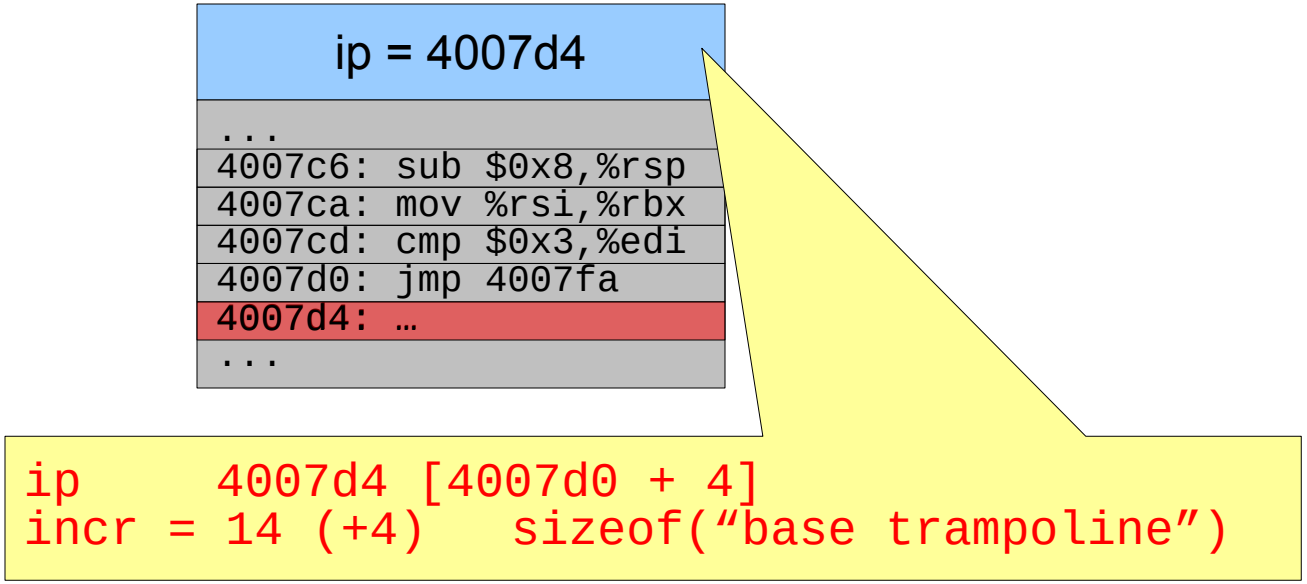

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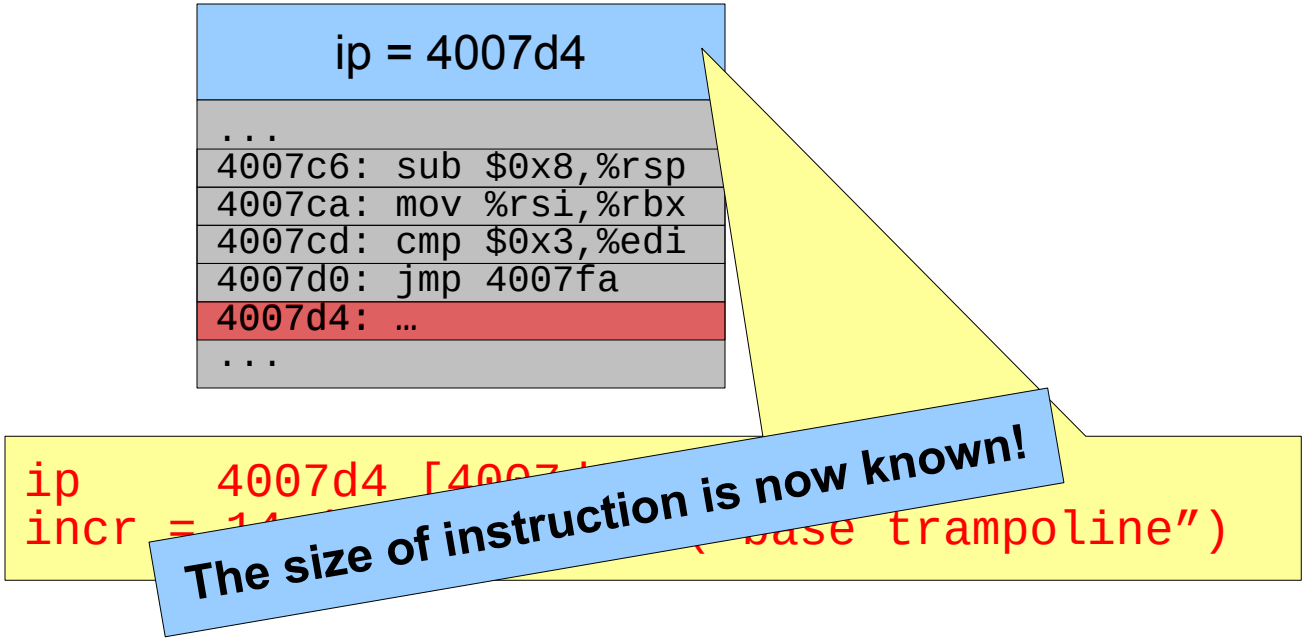

5
Other architectures

Other architectures

Other CPUs...

- 32-bit Intel Architecture is straighforward
  - Just a simple modification of the ABI
- RISC processors are easier
  - Simplified ABI
  - Fixed-size instructions

And other operating system...

- *BSD should not be a problem
  - The `ptrace()` system call changes but offers similar functionalities
  - The ABI compatibility needs to be verified
- MacOS X is problematic

The MacOS X issue

MacOS X `ptrace()` system call is outdated...

- The `task_for_pid()` mechanism replaces it
- The ABI changes
- MacOS X has a complex capability scheme needed for tracing
- Even the LD_PRELOAD mechanism changes

6
Future

In the future...

EZTrace will:

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- instrument functions of static libraries,

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- instrument functions of static libraries,
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- do it easily thanks to a module generator,

```
BEGIN_MODULE
NAME example_lib
DESC "module for the example library"
LANGUAGE C
ID 42

int example_function2(int* array, int array_size)
BEGIN
  RECORD_STATE("running example_function2")
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- and save the world...

...and the ornithorhynchus

Thank you!

http://eztrace.gforge.inria.fr