Do It Live

Measuring Your Applications in Production

Why bother measuring in production?

- Something has gone wrong:
  - Things are slow
  - The system is emitting errors
  - Service is degraded or there is an outage
  - Users are unhappy
- Reproducing the problem in an artificial environment is too difficult or time consuming
- You simply do not know how to reproduce the problem

Ultimately

Production is Reality

Everything else is at best a proximity

You need to be able to solve problems in production,

but more importantly

Understanding the character of your workloads
is critical to their successful operation.

The more you understand the software you are
running the more successful you will be at running it.

Debugging is not mearly the act of making bugs go away. It is the act of **understanding** and **gaining new knowledge** about the way the system works.

- Bryan Cantrill (goto; 2017)

Solve Problems

&&

Understand our Software

Methods
Tools
Practice

Methods

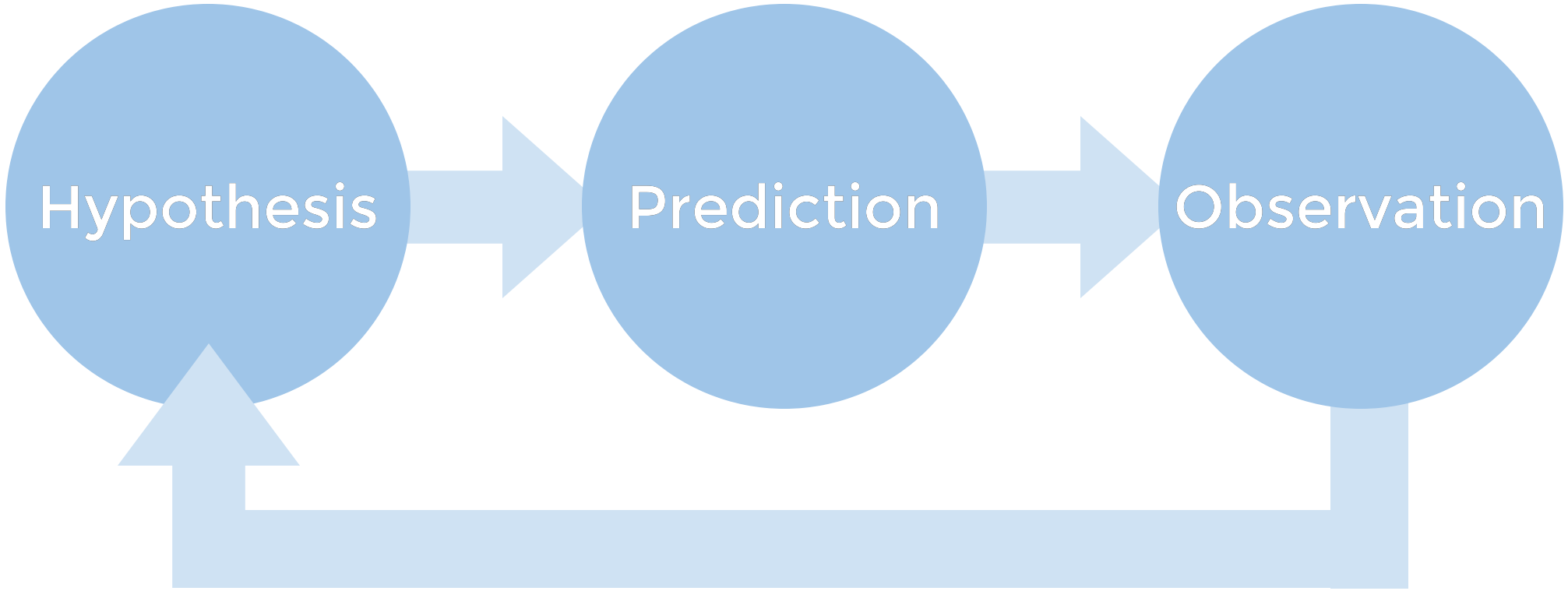
Tools

Practice

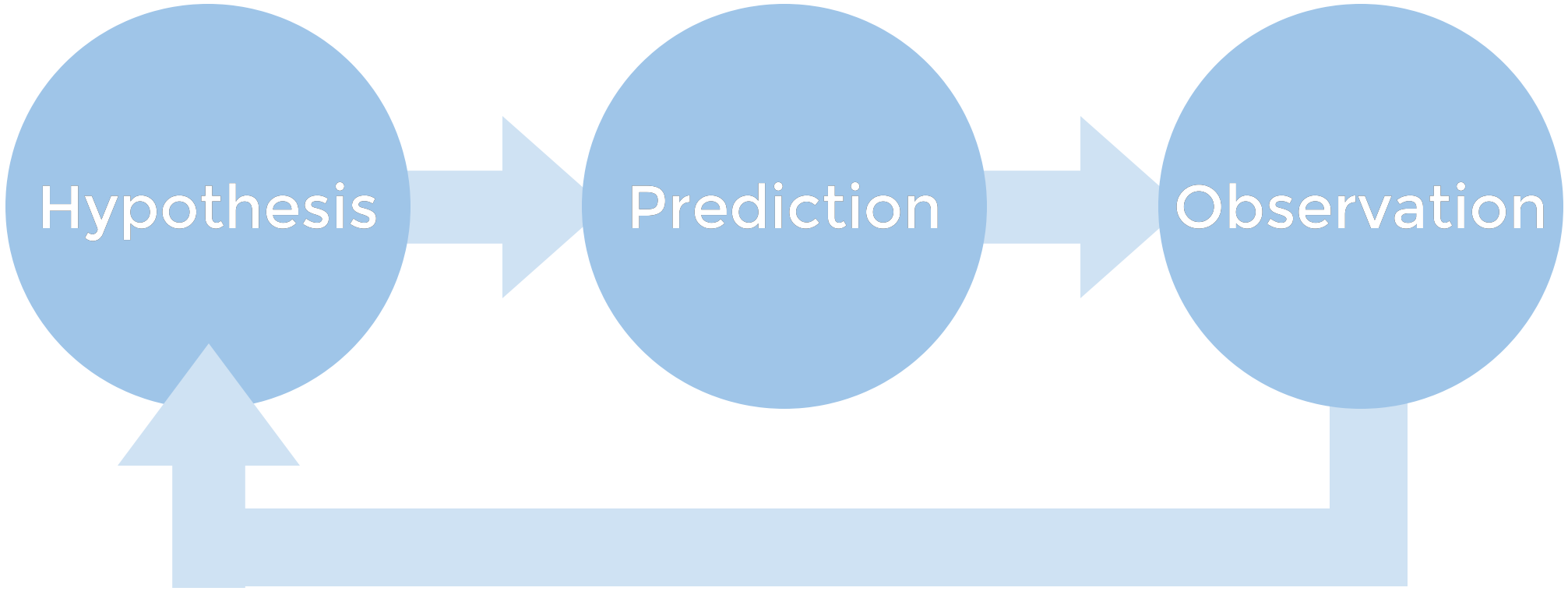
The **Scientific Method**

STAND BACK

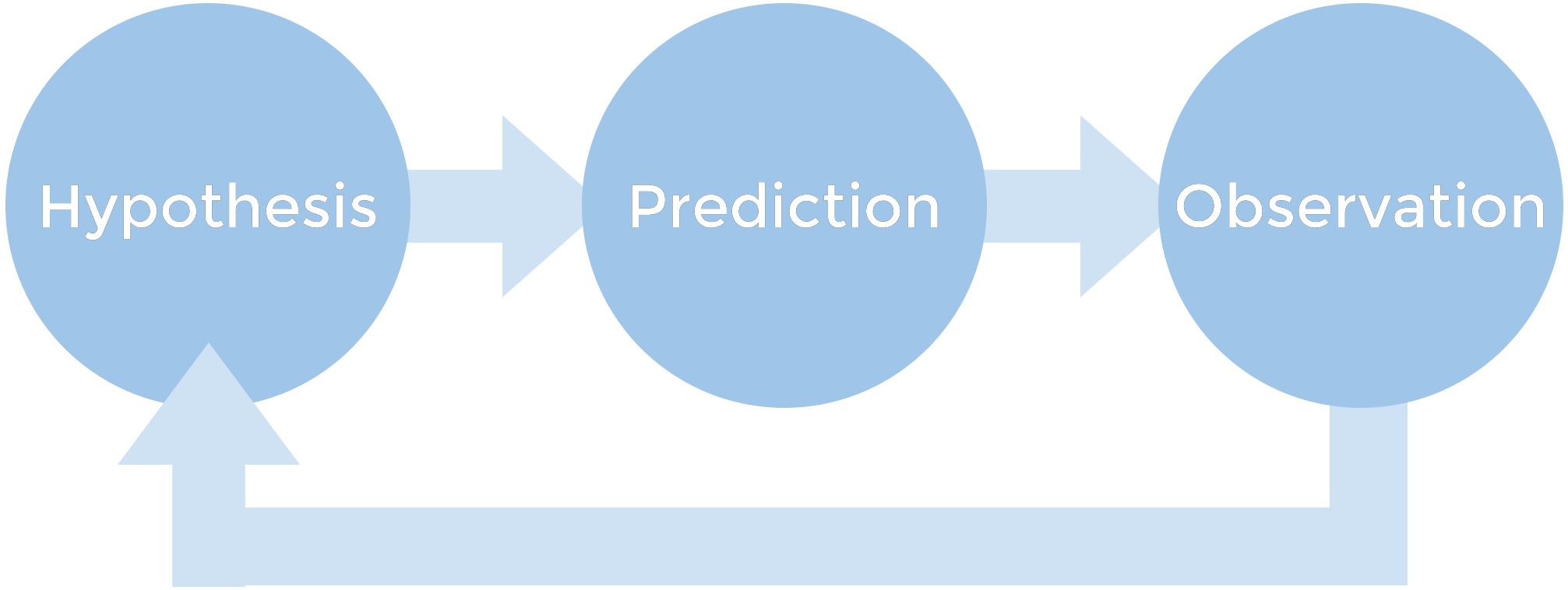
I'M GOING TO TRY SCIENCE


Hypothesis
Prediction
Observation

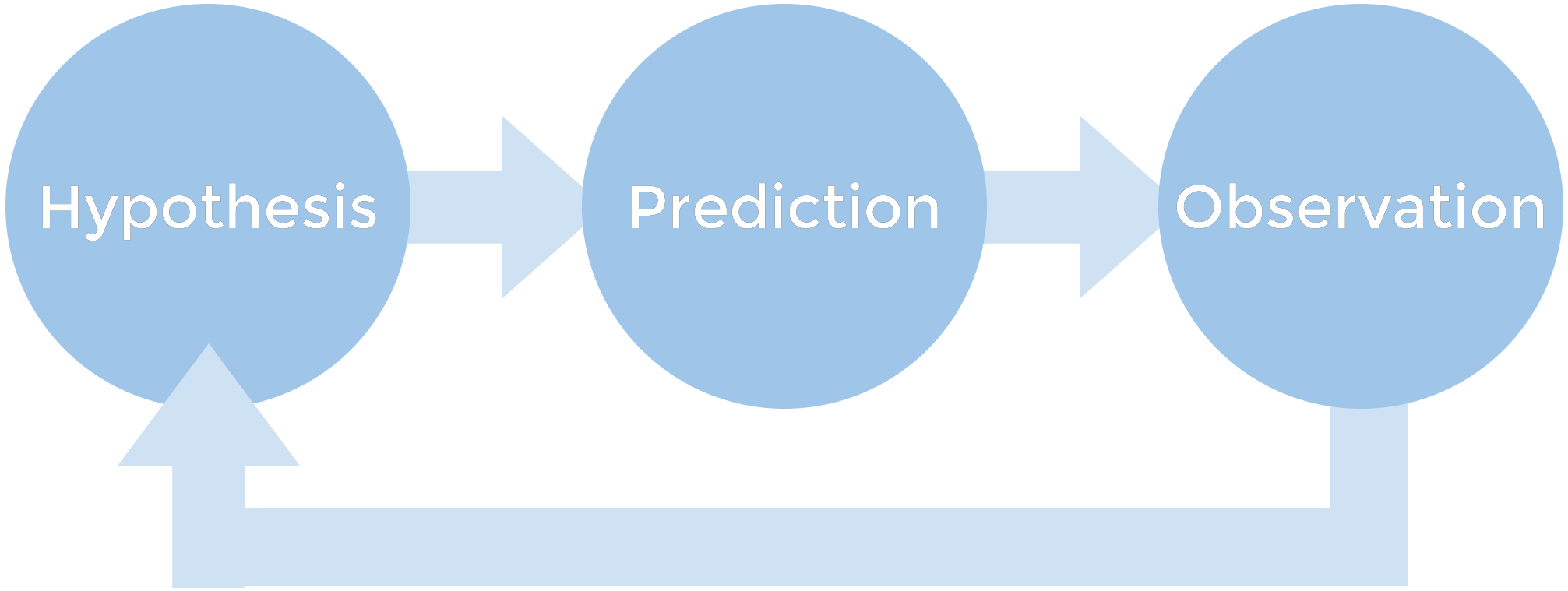
Make a Guess

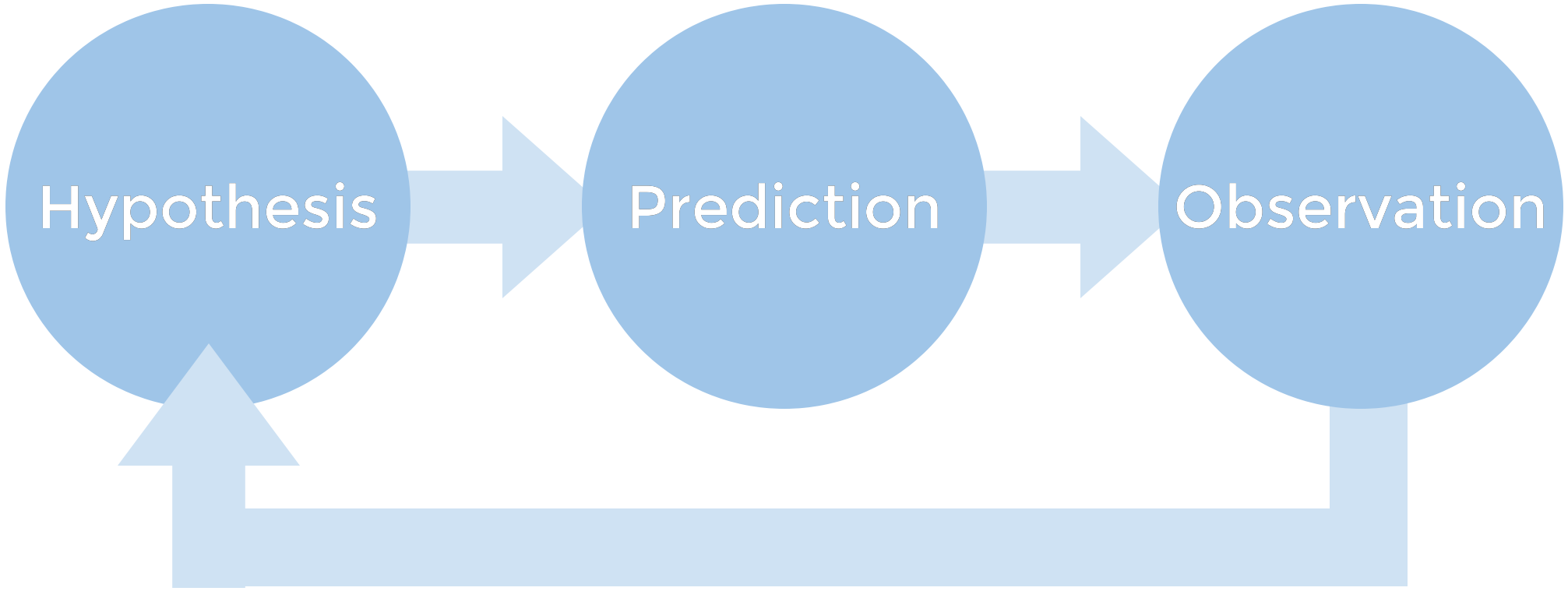


Compute the Consequences of the Guess

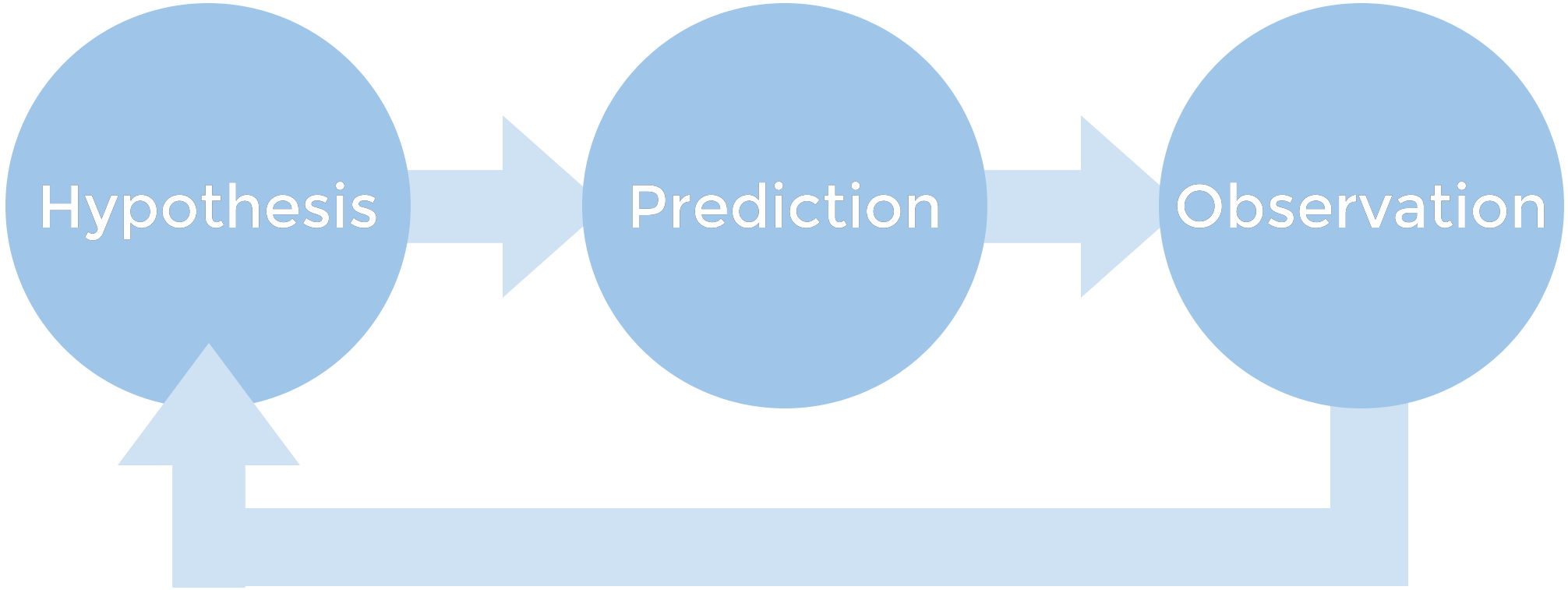


Compare with Reality

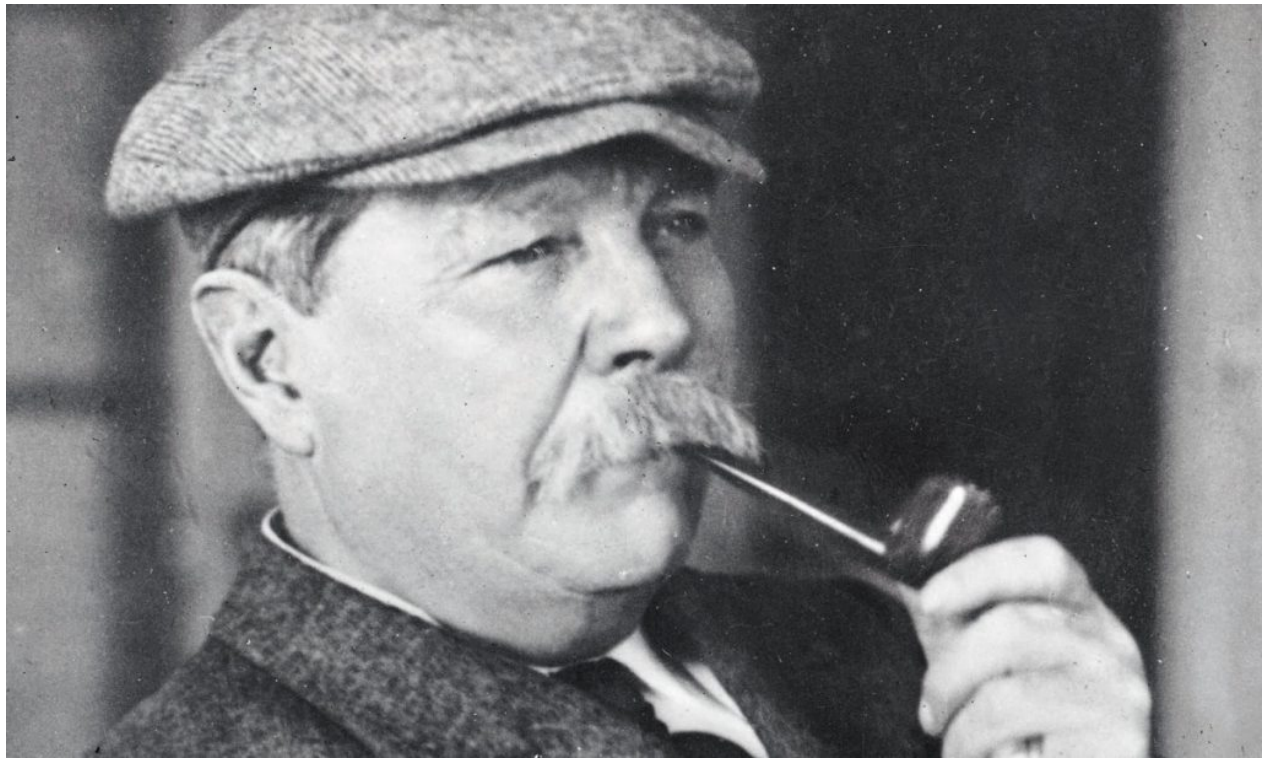



Hypothesis
Prediction
Observation
Inform New Guesses

Assumes you are operating in the context of peer review where your hypotheses will put under high scrutiny



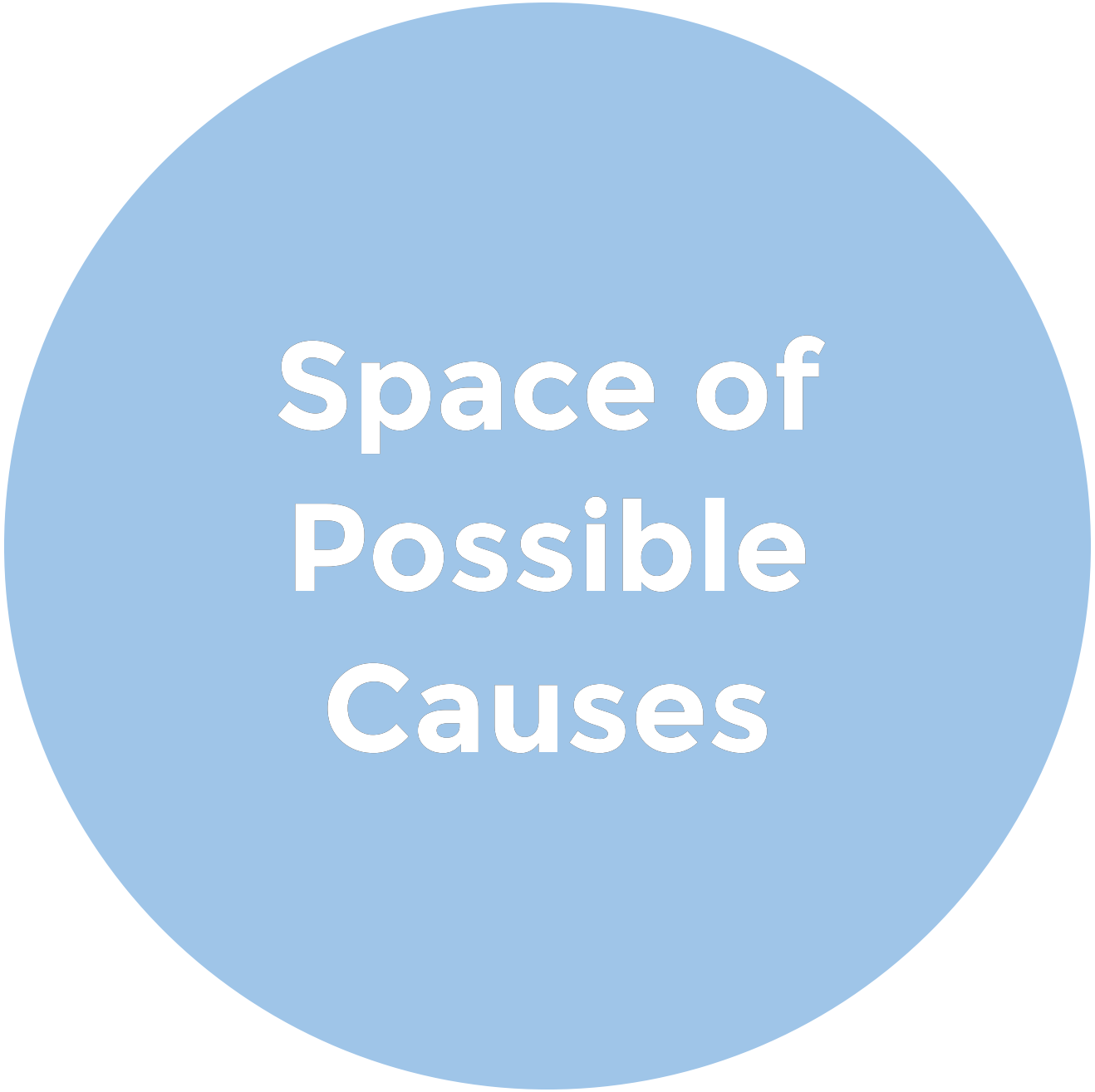
Assumes you have prior data to form a hypothesis



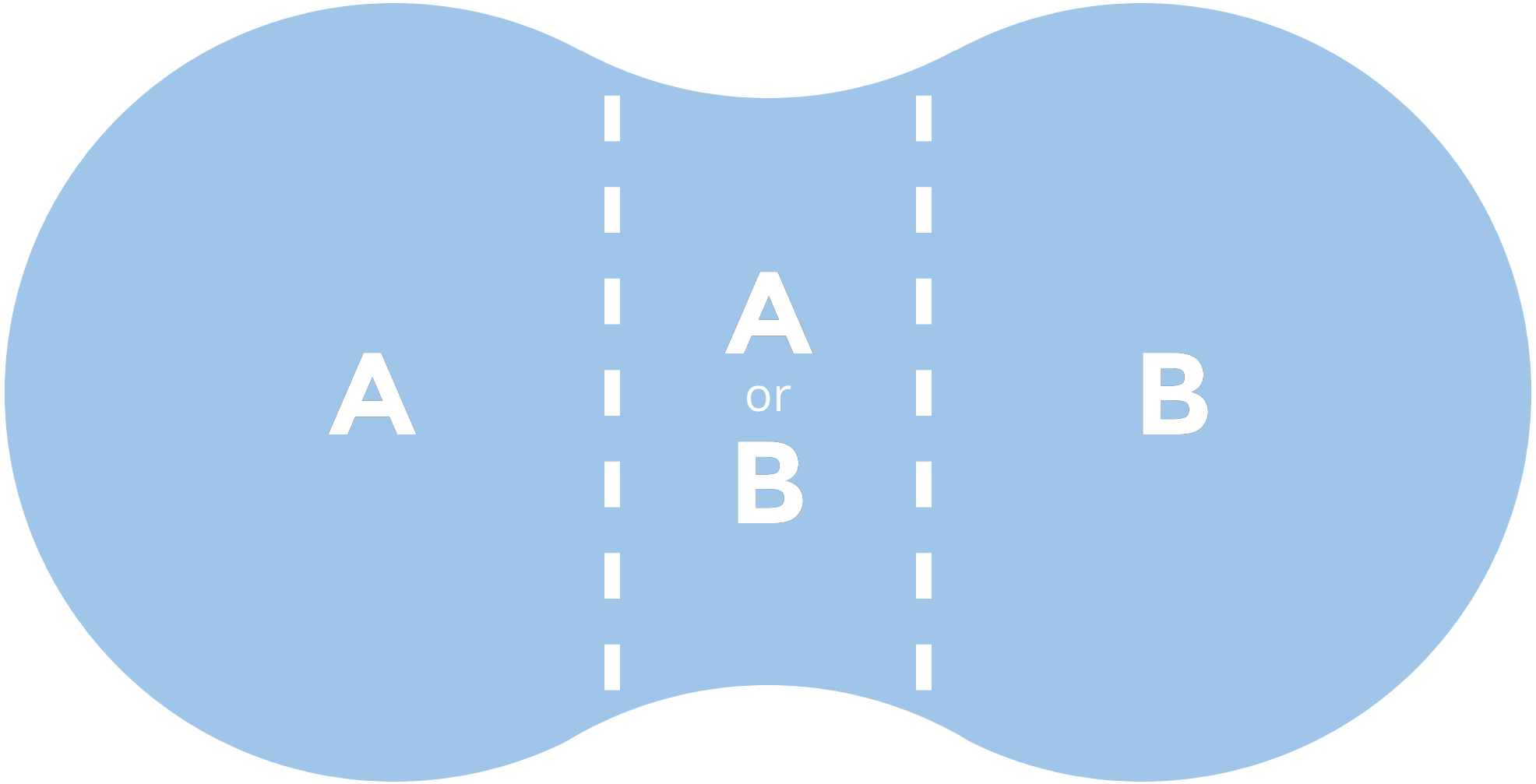
It is a **capital mistake** to theorize **before one has data**. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts.

- Sir Arthur Conan Doyle (A Scandal in Bohemia)

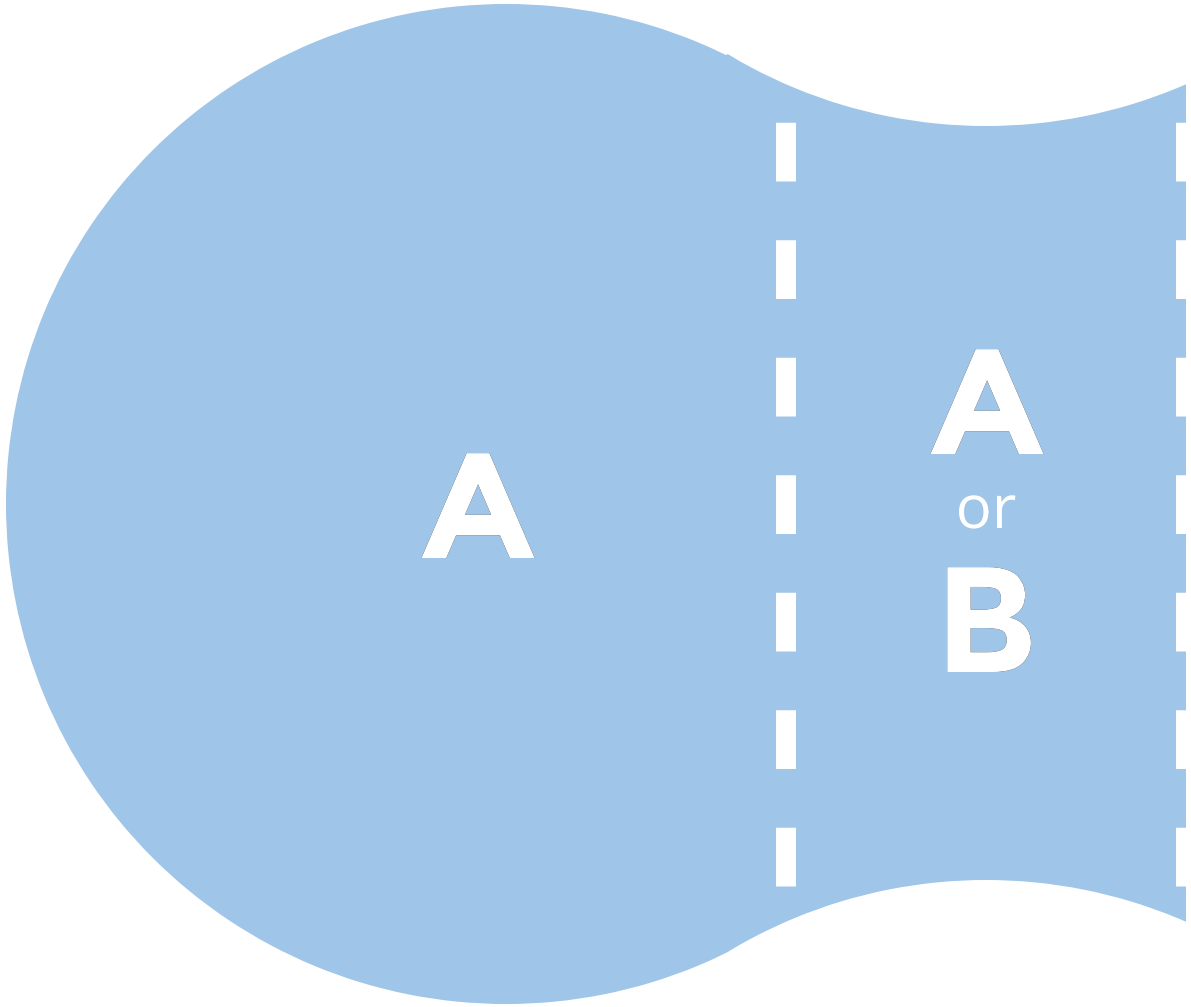
Ask **Questions**, Get **Answers**


Space of
Possible
Causes

A **Question** Divide the Possibility Space



An **Answer** Eliminates Possibilities

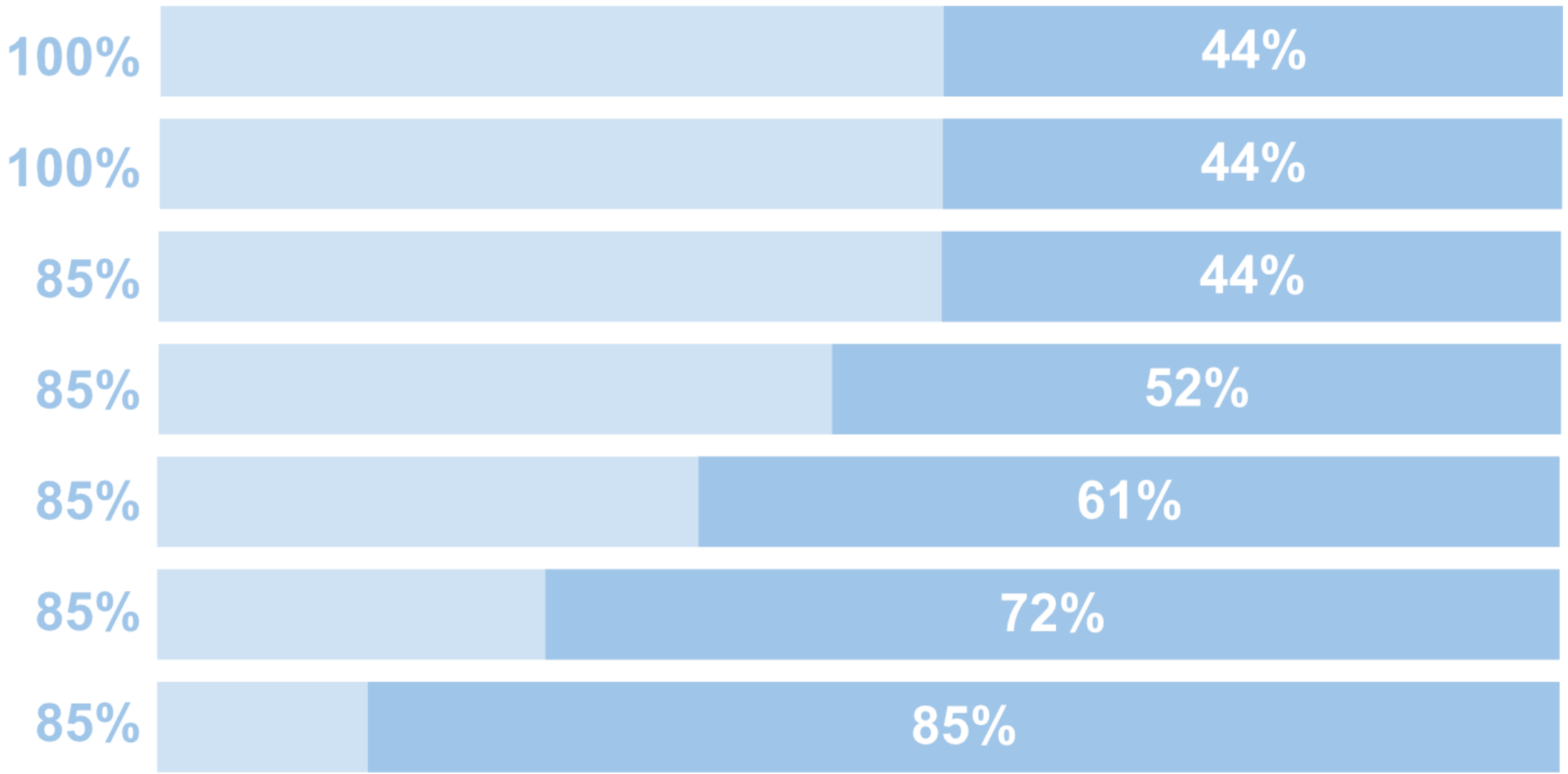



Space of
Possible
Causes


Space of
Possible
Causes


Space of
Possible
Causes

It is **Critical** that you are confident in your **Answers**


100%
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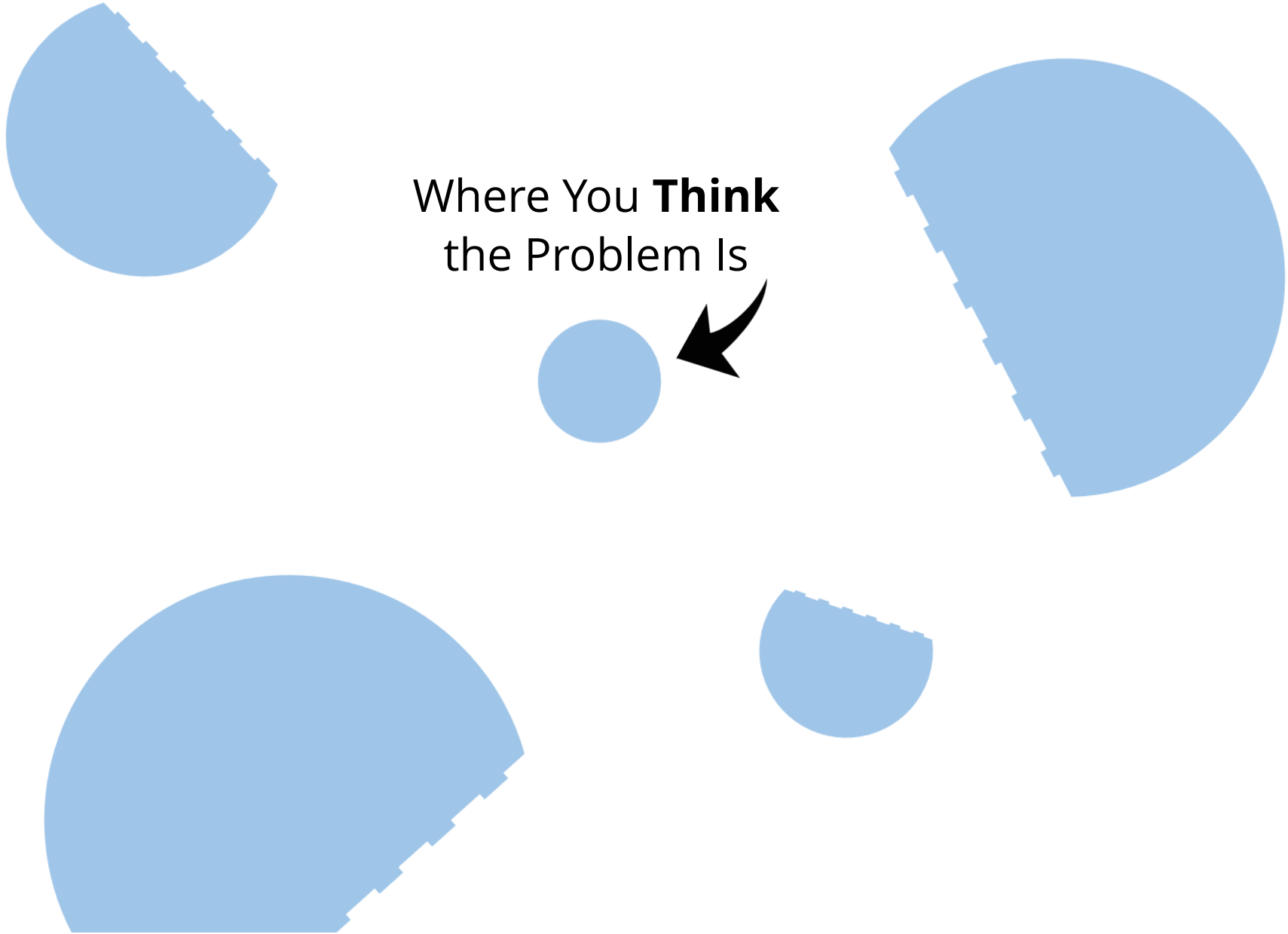
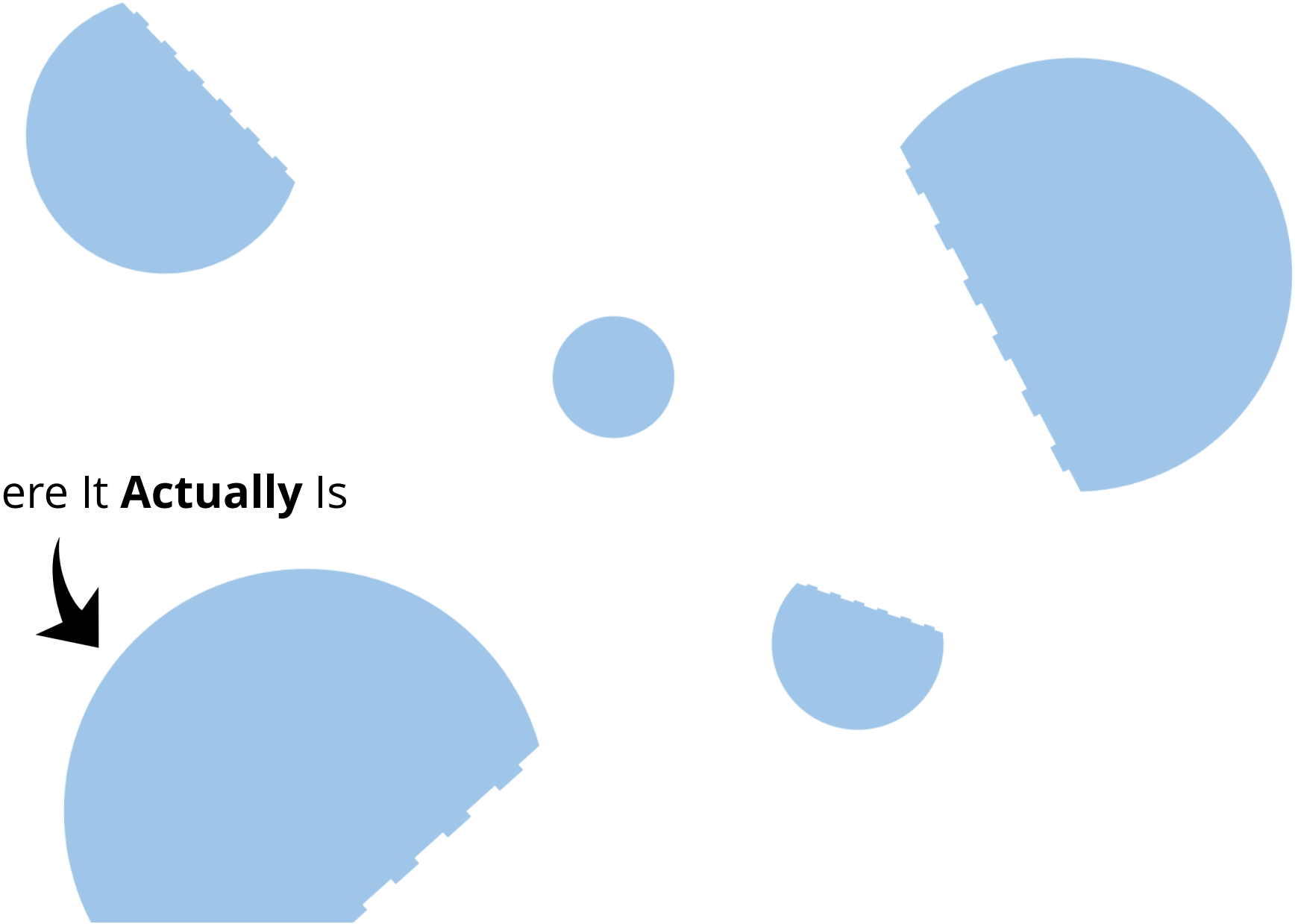
85%


Where You **Think**
the Problem Is


Where It **Actually** Is

Posing a Question does not help
if you can not get an Answer

We need **Tools** that can give us
Answers to our Questions

Not having the right tools constrains the
sort of Questions you can ask

Methods

Tools

Practice

We want tools that can answer arbitrary questions about our software

Which means intercepting any point of execution

Without restarting the process

With as low overhead as possible

Being able to read and write to memory and registers

Collect data across multiple processes and the kernel

And do it all safely

(without crashing the processes, panicking the kernel, or corrupting state)

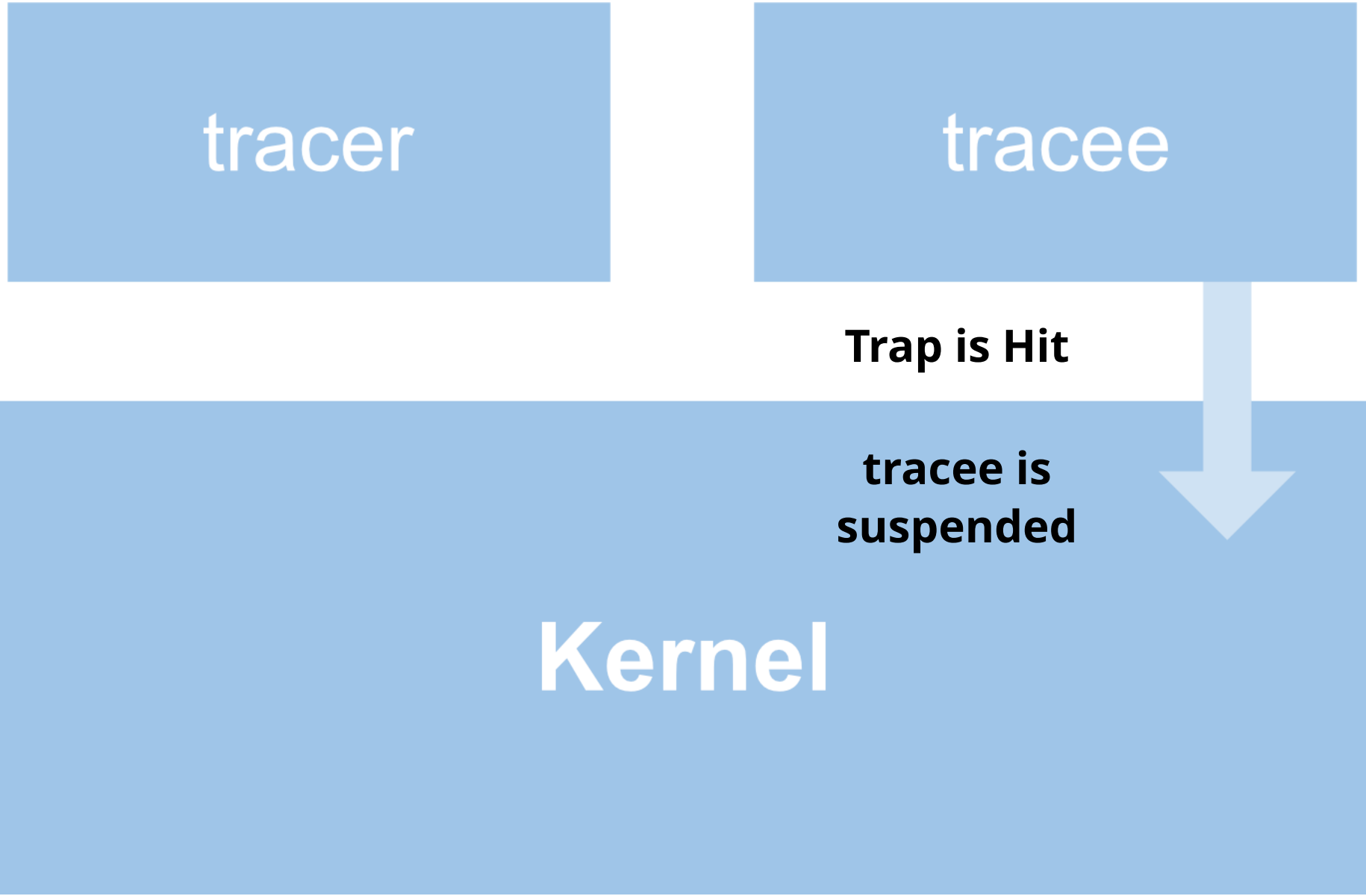
Debuggers are Awesome

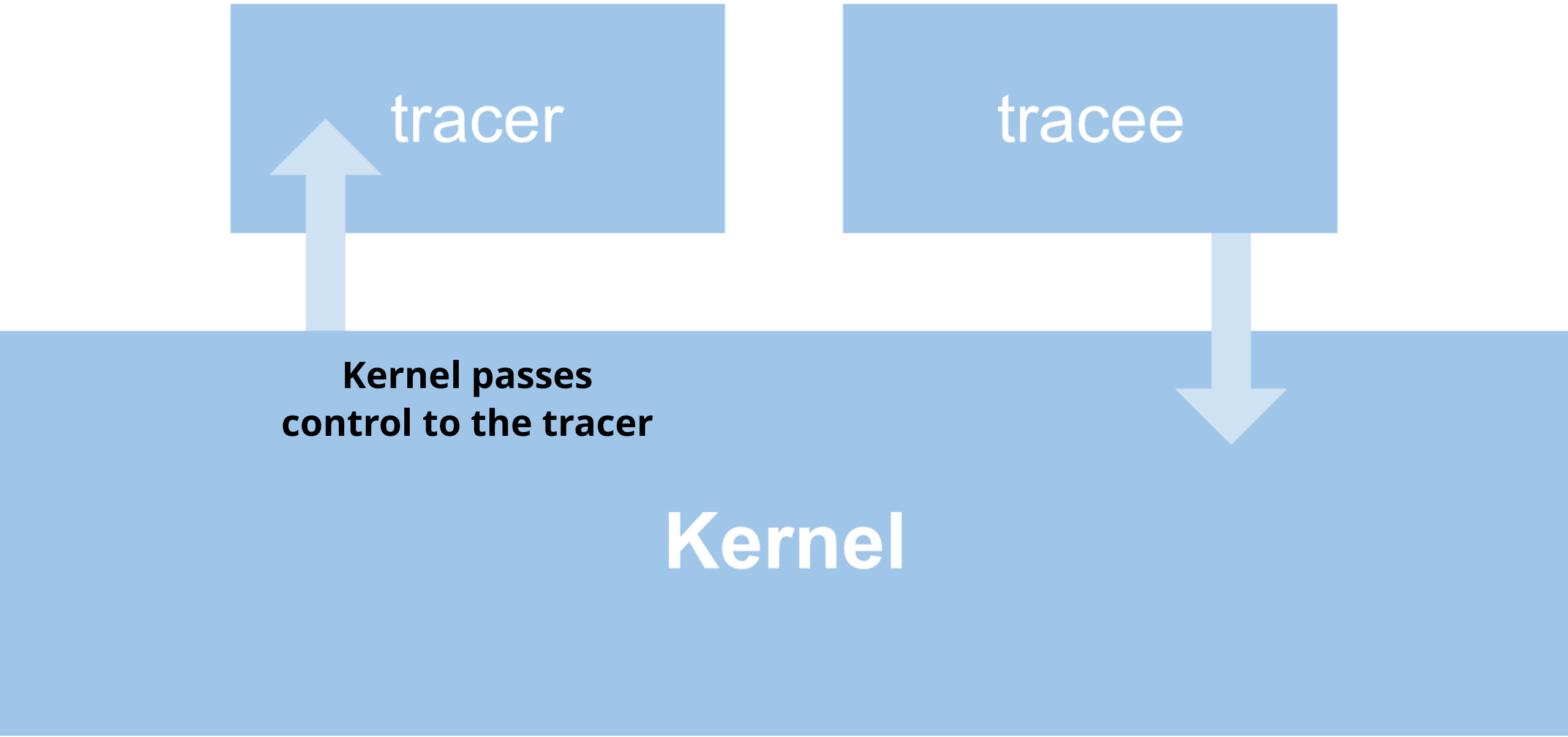
Starting GDB

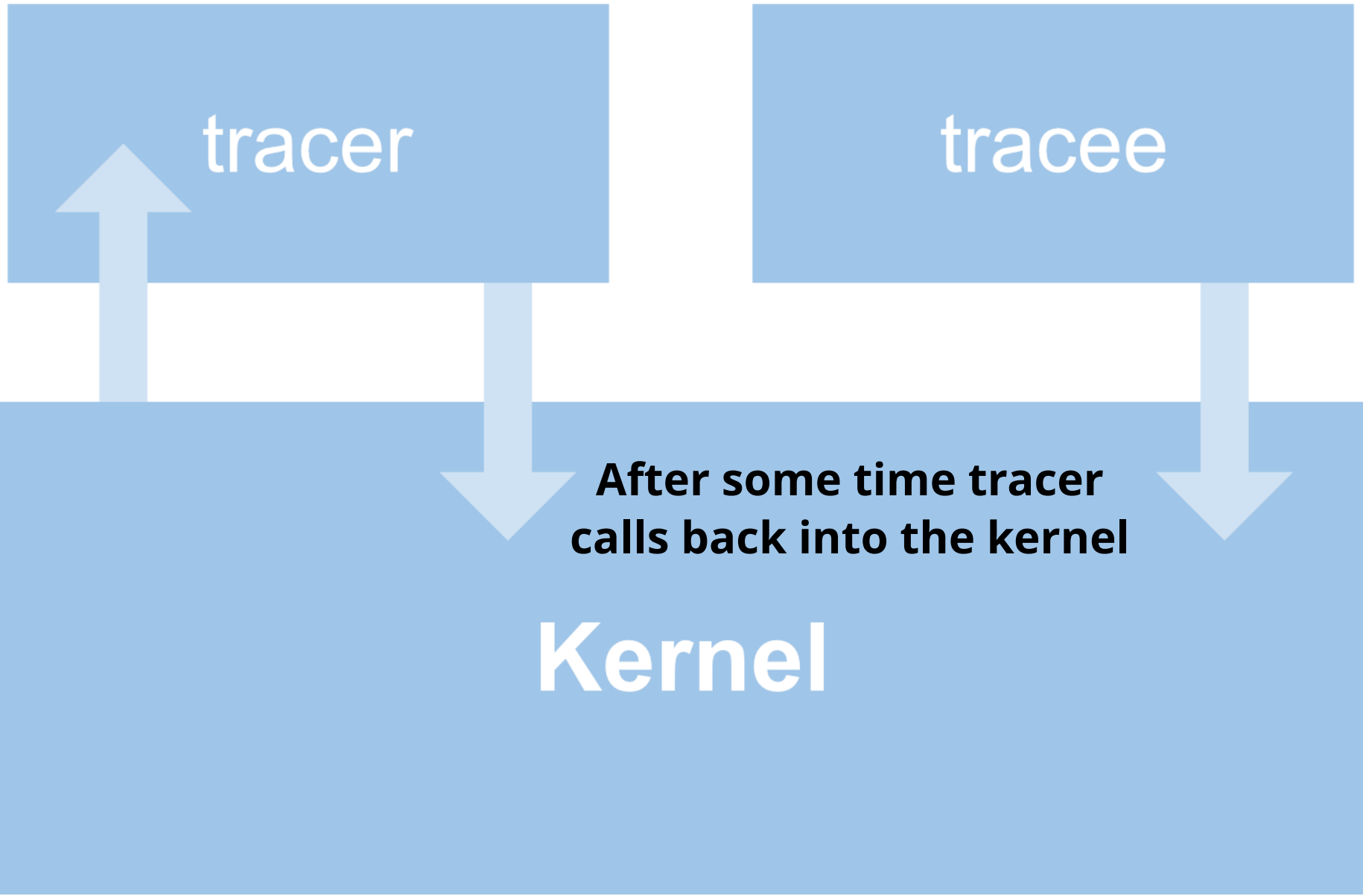
ptrace (Process Trace)

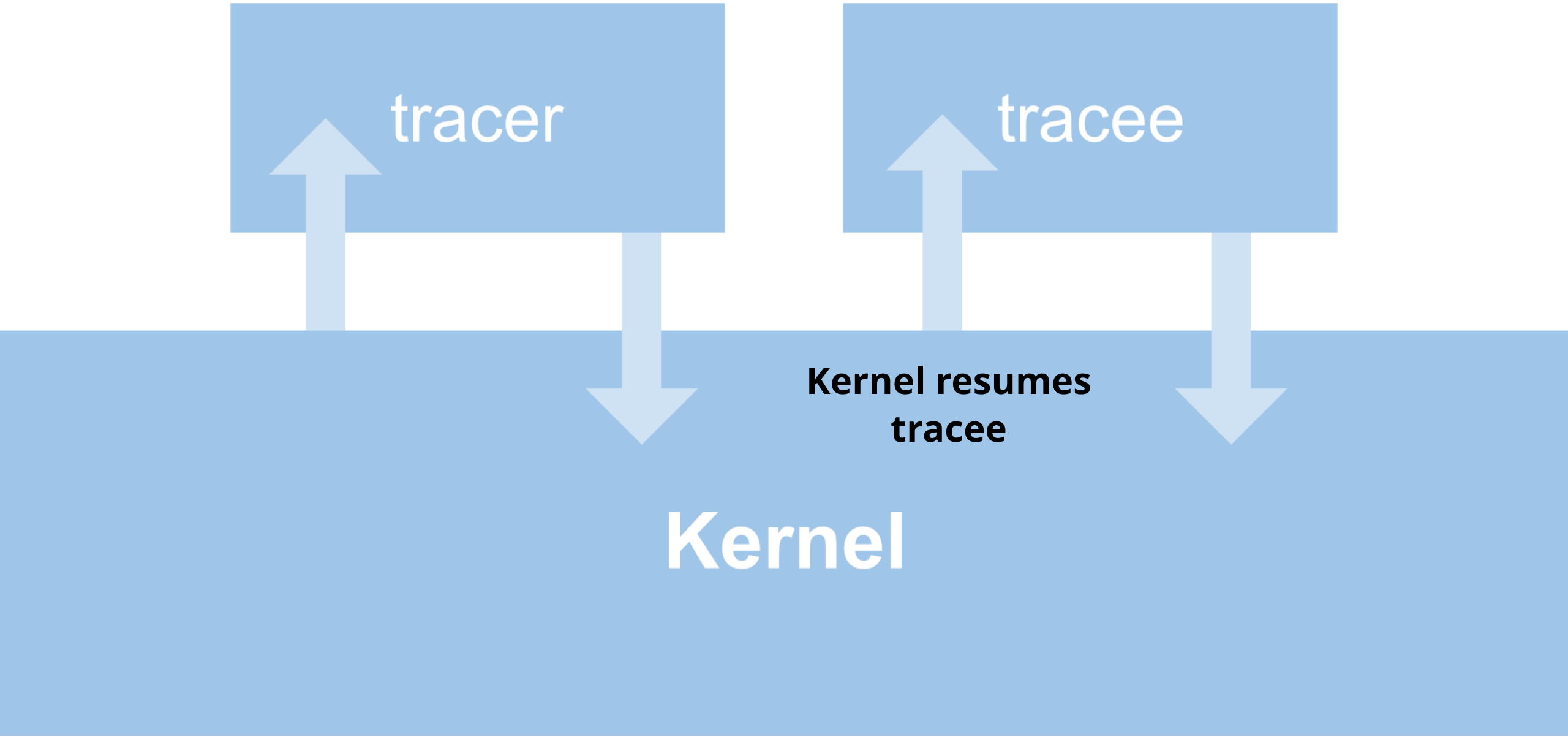
- Allows a tracer process to control the execution of a tracee process
  - intercept signals
  - intercept syscalls
  - read and write to registers
  - read and write to memory (including .text)
  - single step through the tracee
- Writing to .text allows you to set breakpoints
- When tracer is running the tracee's execution is typically suspended
- Well supported on virtually every language/platform

Kernel


tracer
tracee
Trap is Hit
tracee is
suspended
Kernel


tracer
tracee
Kernel passes
control to the tracer
Kernel


tracer
tracee
After some time tracer
calls back into the kernel
Kernel


tracer
tracee
Kernel resumes tracee
Kernel

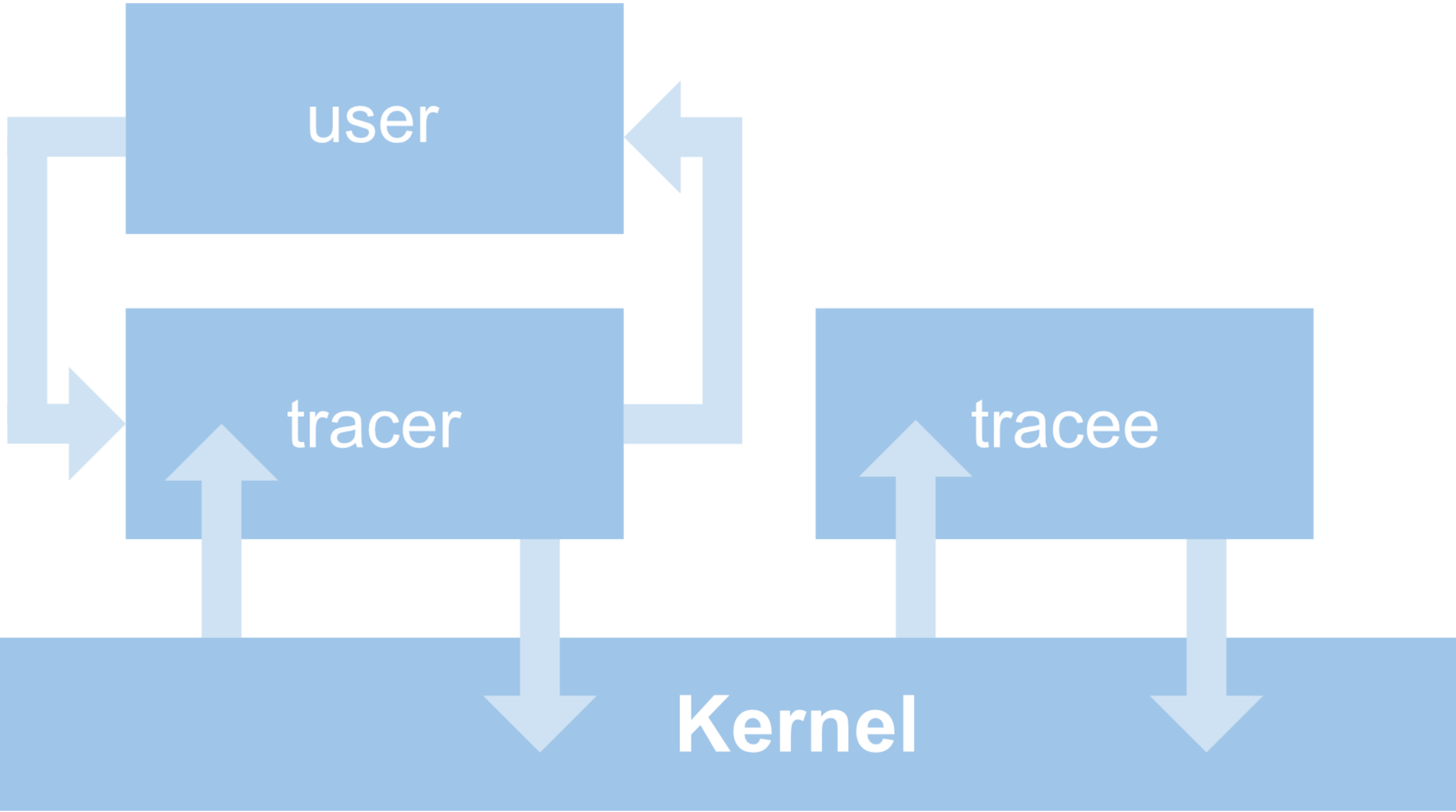
Main Problem with ptrace:

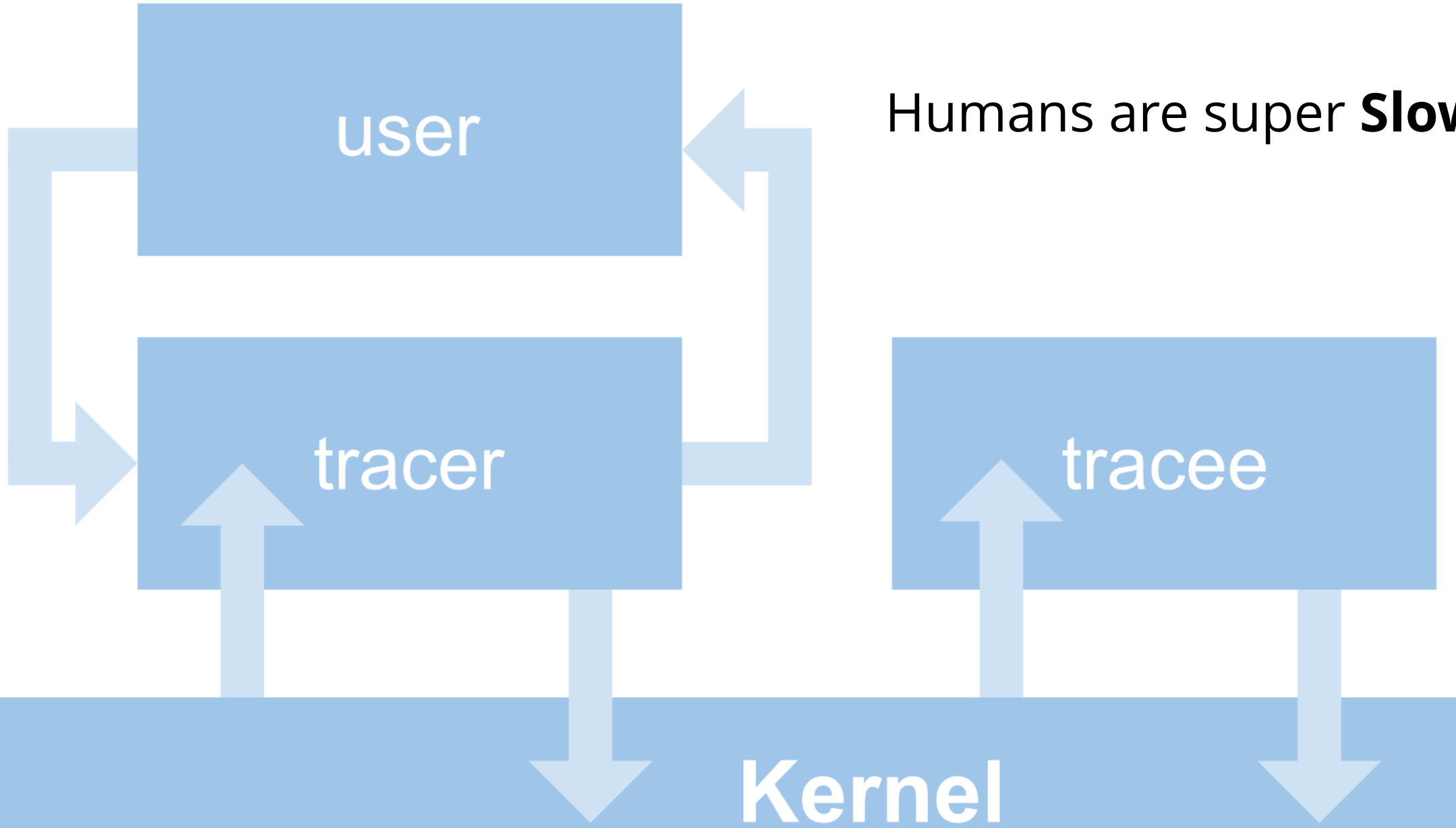
Suspended Execution

Your program is doing **no** work while it is suspended!

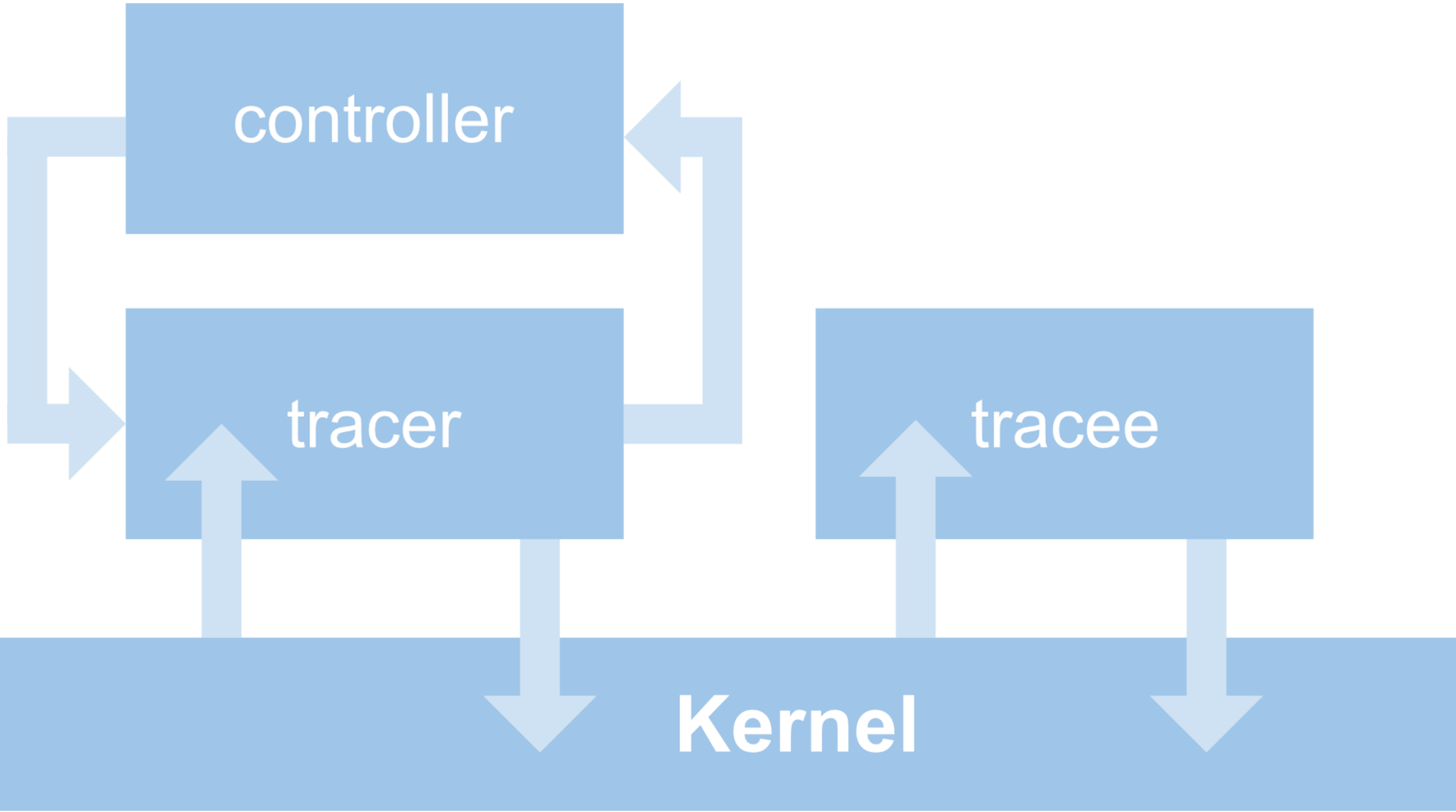
If the tracer is slow to yield back this will cripple a process.

The tracer is usually blocked on **user** input.


user
tracer
tracee
Kernel



Humans are super **Slow!**


controller
tracer
tracee
Kernel

go-diodes bug


agent


agent


agent

```
func main() {
        d := diodes.NewOneToOne(1<<12, diodes.AlertFunc(func(int) {}))

        go func() {
                for {
                        write(d)
                }
        }()
        for {
                read(d)
        }
}

func write(d *diodes.OneToOne) {
        d.Set(genData)
}

func read(d *diodes.OneToOne) {
        d.TryNext()
}
```

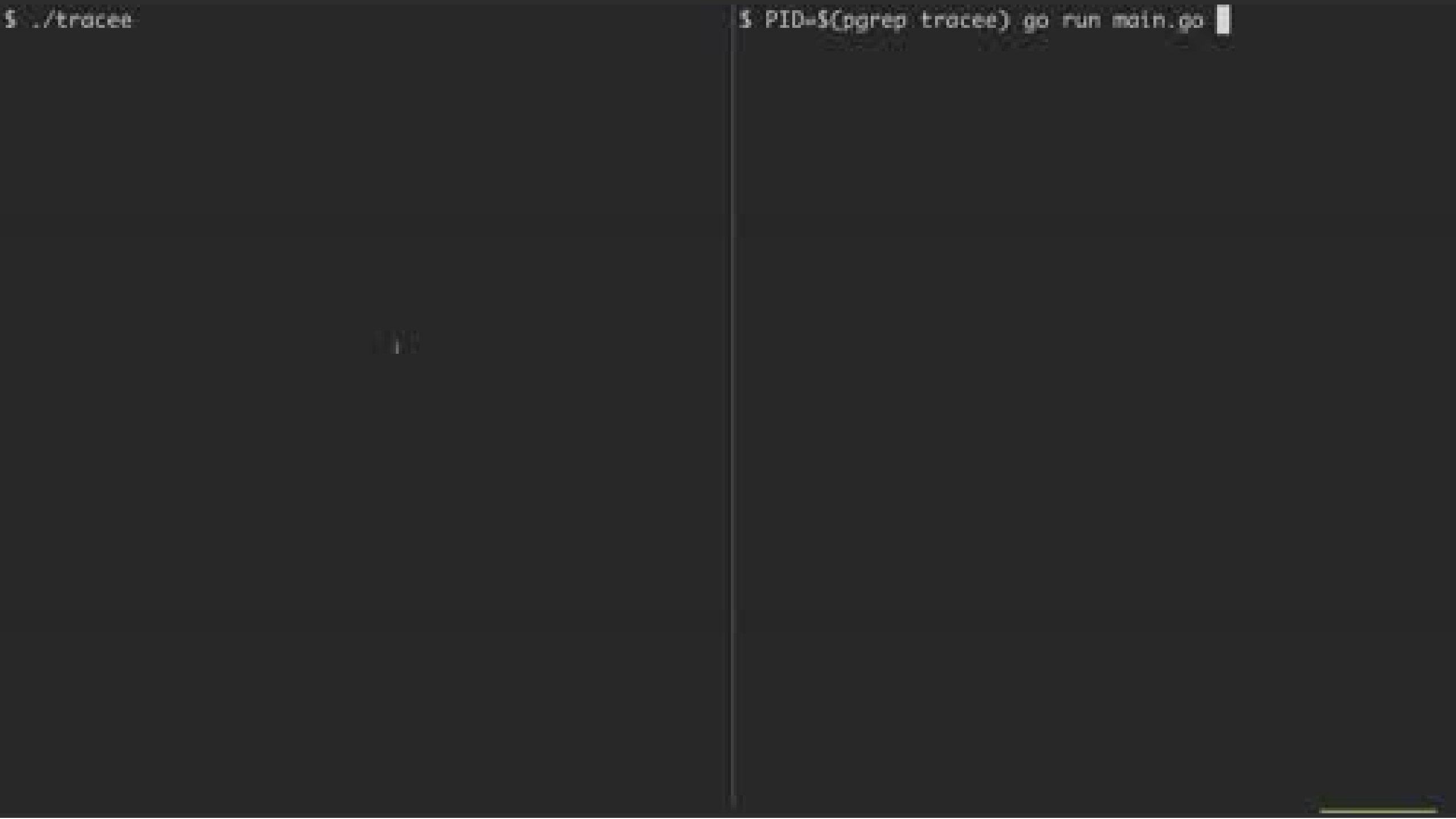
```
func init() {
        cmd = exec.Command("dlv", "attach", os.Getenv("PID"))
        childIn, _ = cmd.StdinPipe()
        childOut, _ = cmd.StdoutPipe()
}

func main() {
        cmd.Start()

        // resume tracee
        fmt.Fprint(childIn, "continue\n")

        // read, filter and report data
        go reader(childOut)

        for {
                // sample data periodically
        }
}
```

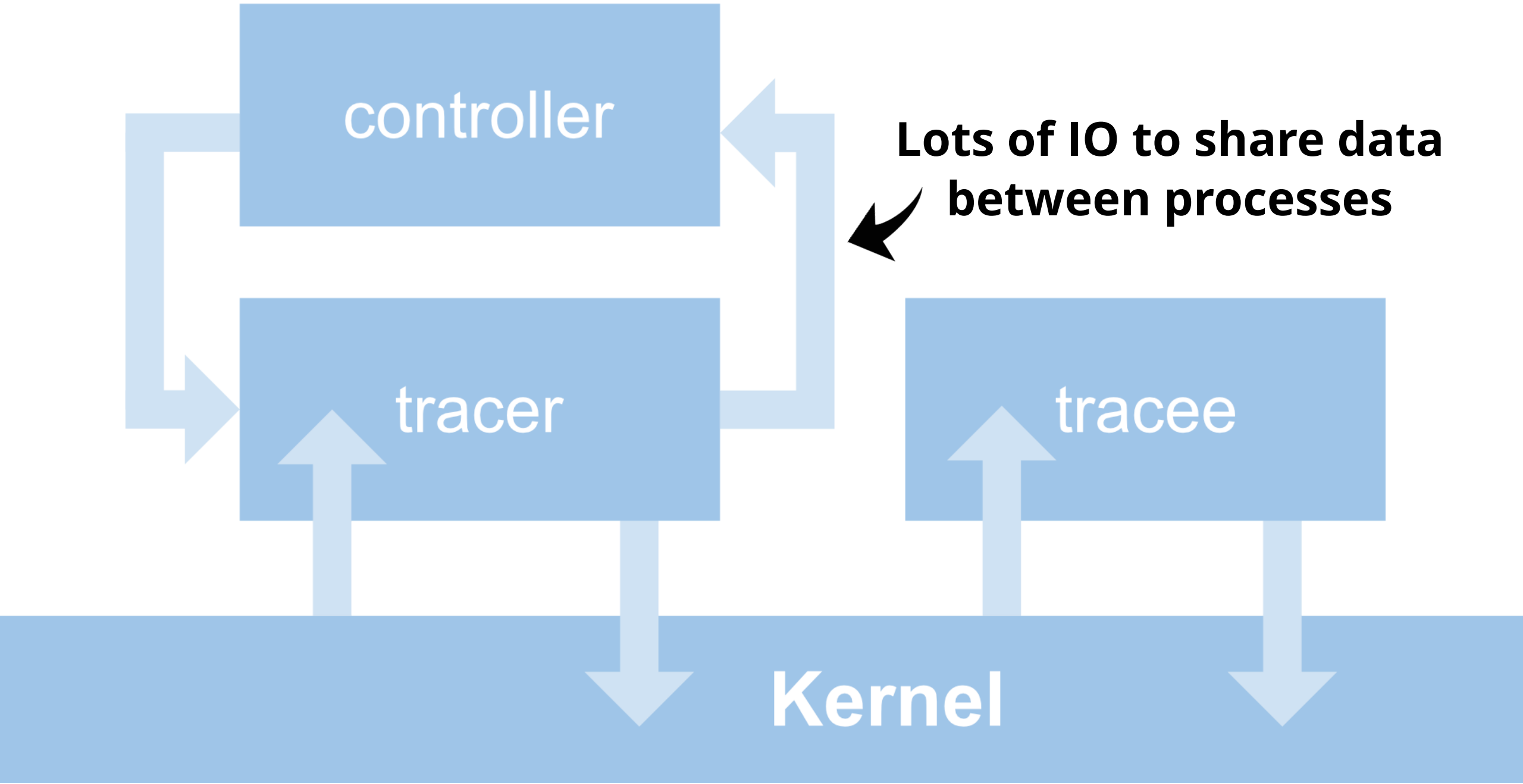
```
time.Sleep(time.Second)
cmd.Process.Signal(os.Interrupt)

if timeToExit() {
        fmt.Fprint(childIn, exit)
        return
}

fmt.Fprint(childIn, sample)


const sample = `break main.write
continue
print d.writeIndex - d.readIndex
clearall
continue
`
const exit = `clearall
quit
no
`
```

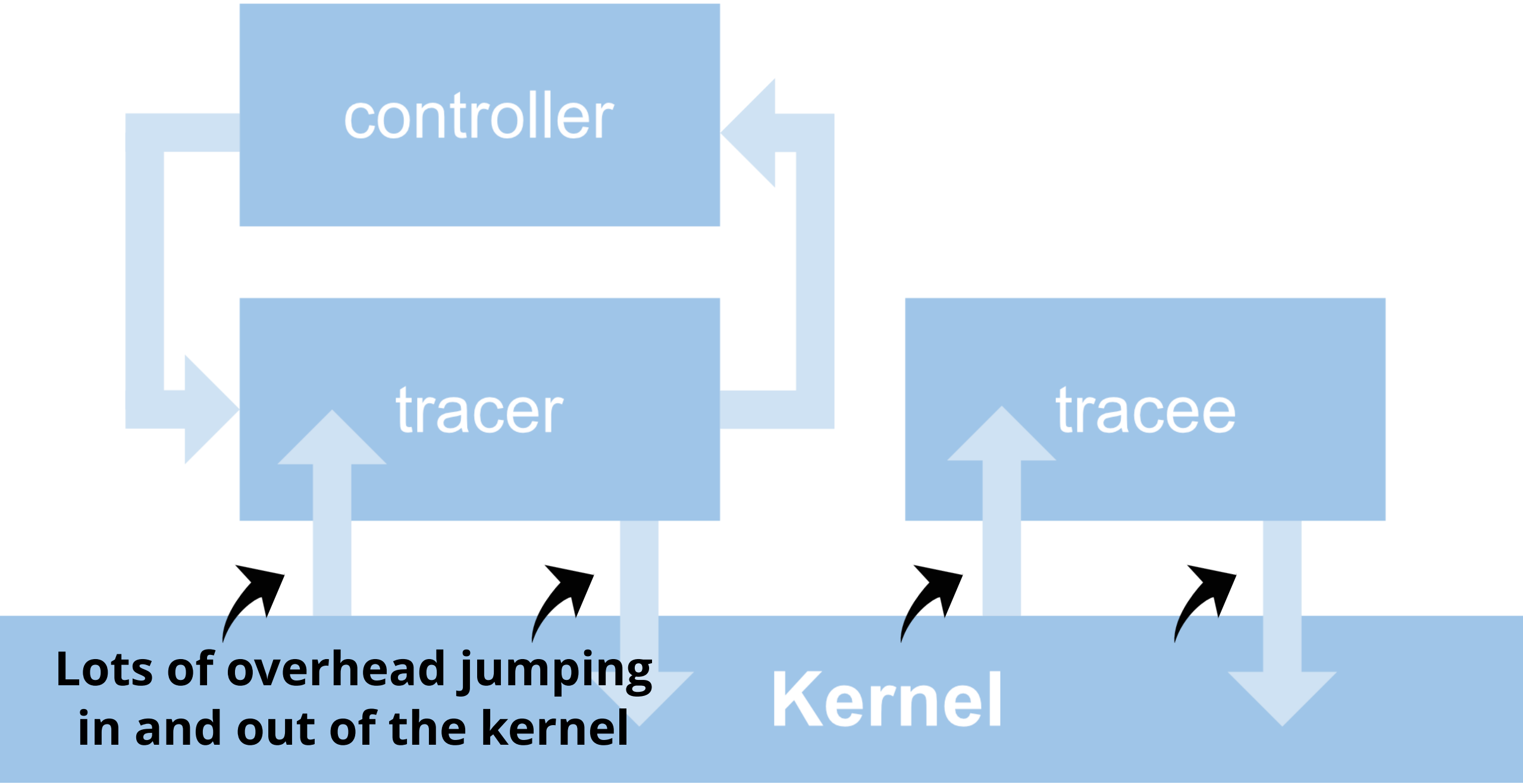
```
$ ./tracee
```

```
$ PID="$(pgrep tracee)" go run main.go
```

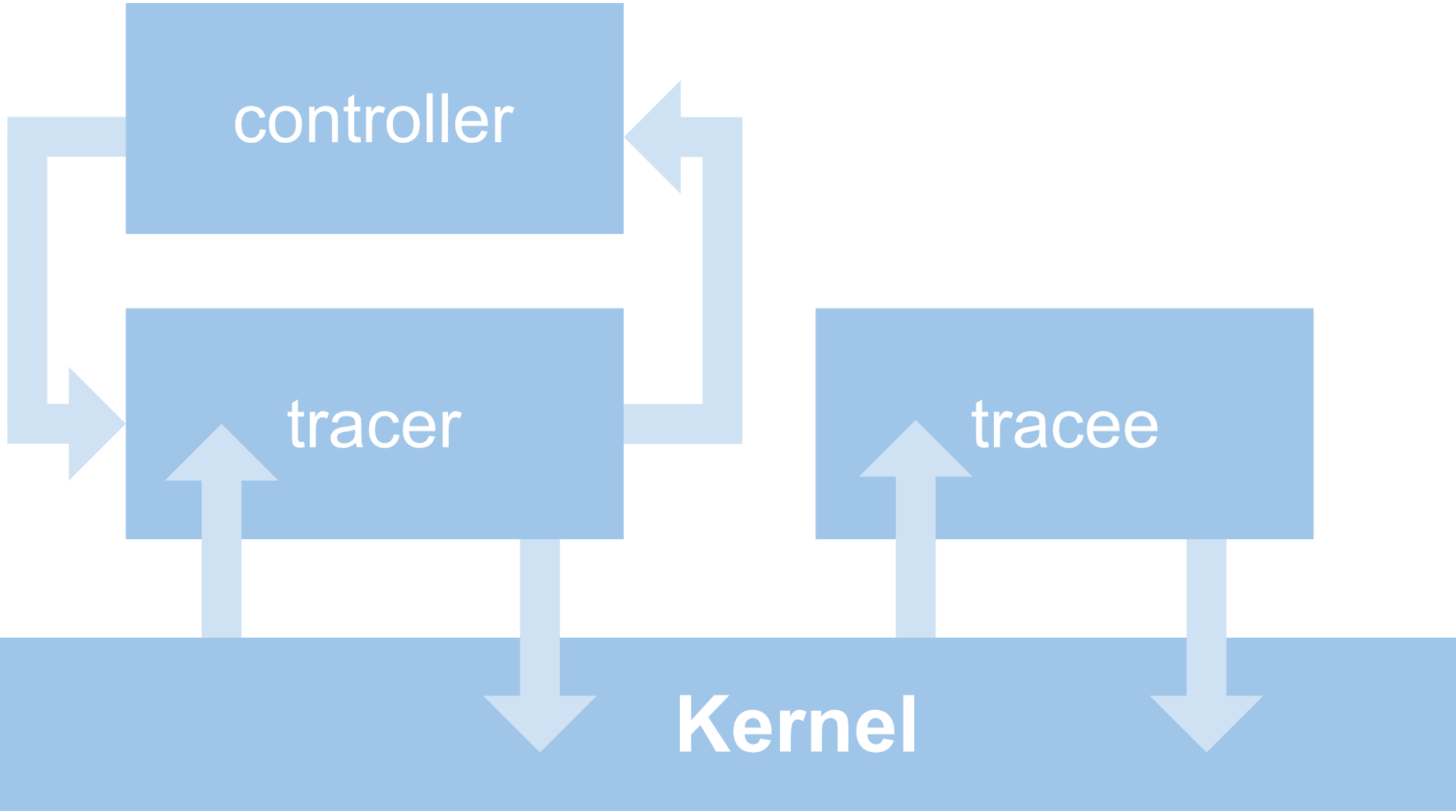
This only works for
low frequency sampling

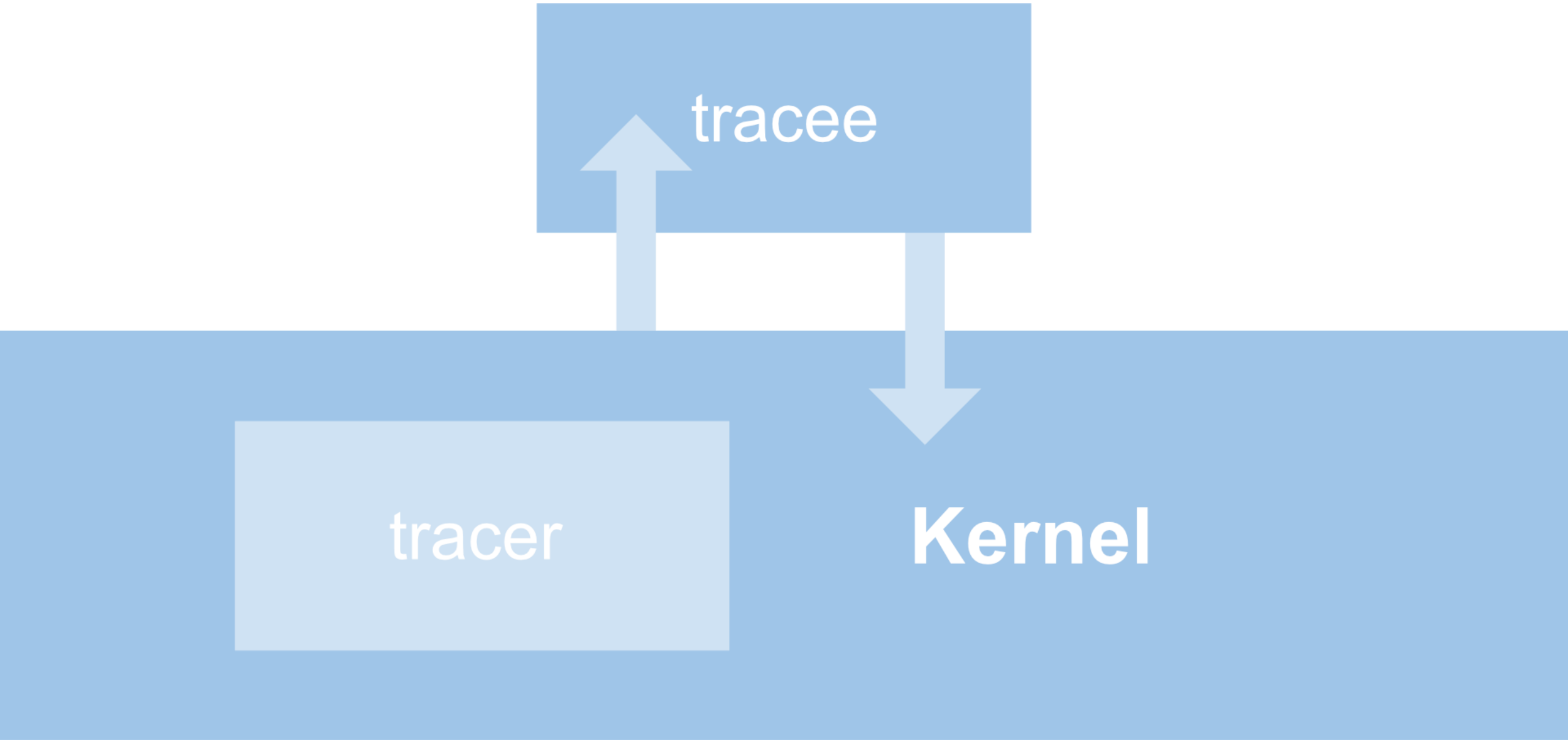

$ ./tracee
$ PID=$(pgrep tracee) go run main.go


controller
tracer
tracee
Kernel
Lots of IO to share data between processes


controller
tracer
tracee
Kernel
Lots of overhead jumping
in and out of the kernel

Is there A Better Way?


controller
tracer
tracee
Kernel


tracee
tracer
Kernel

BPF can do this!

What is BPF?

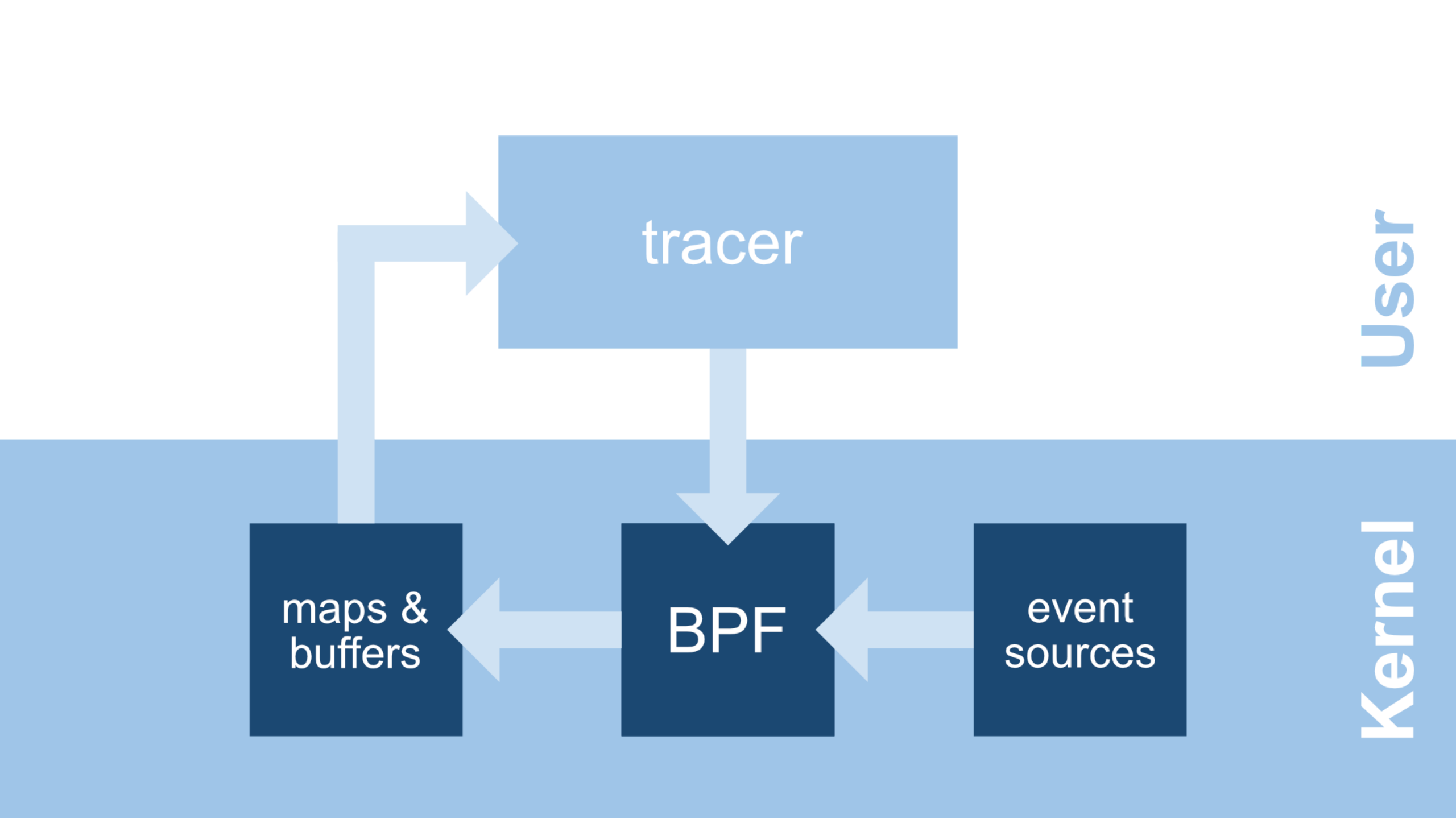
- BPF is a custom instruction set that you can use to build programs and inject them into the kernel.
- The kernel validates the program to make sure it is safe and then compiles it for your architecture so it runs fast.
- You can then attach these programs to various events.
- It was originally created for programs that do packet filtering with little overhead, hence the name (Berkeley Packet Filter).
- For example something like this:

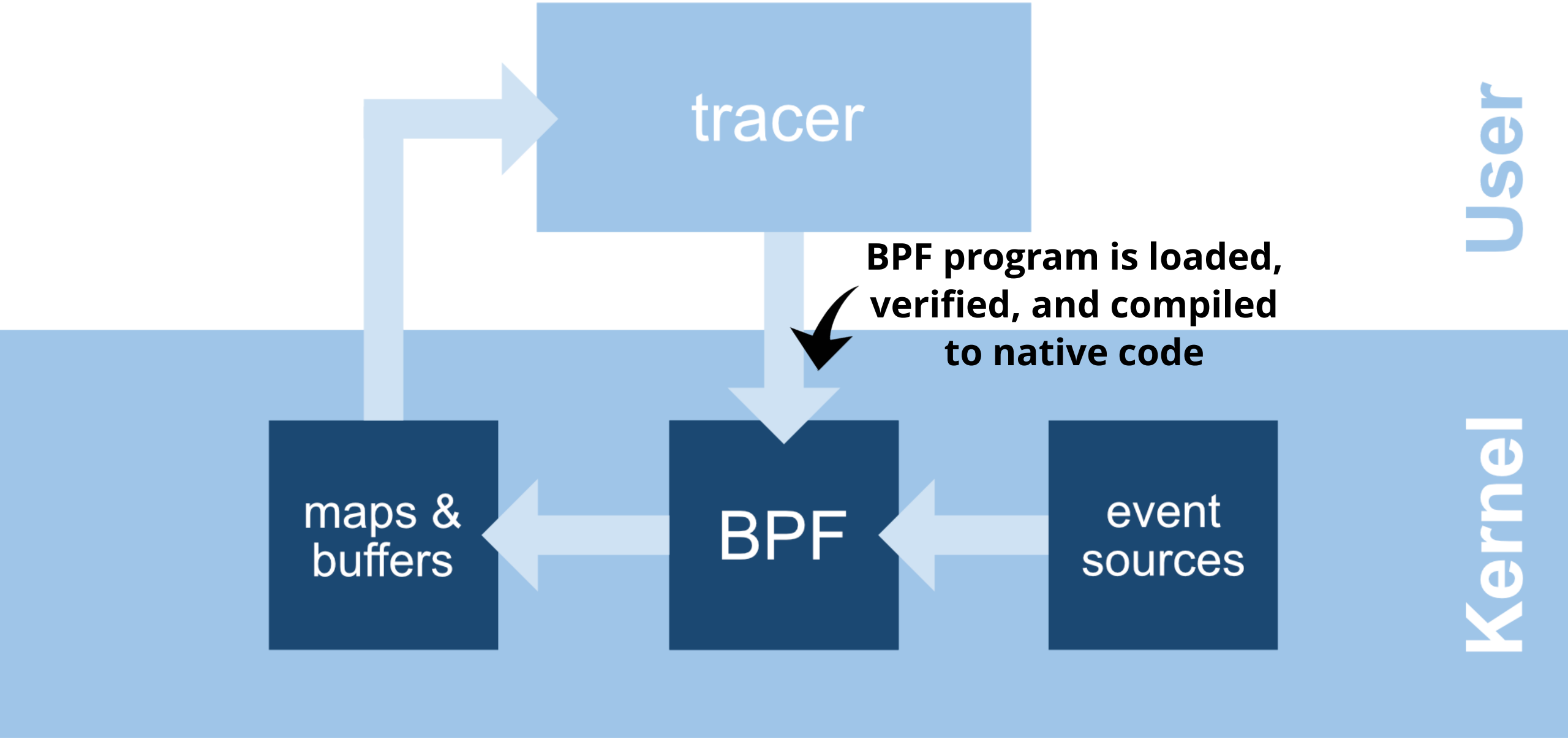
```
tcpdump src 10.5.2.3 and dst port 3389
```

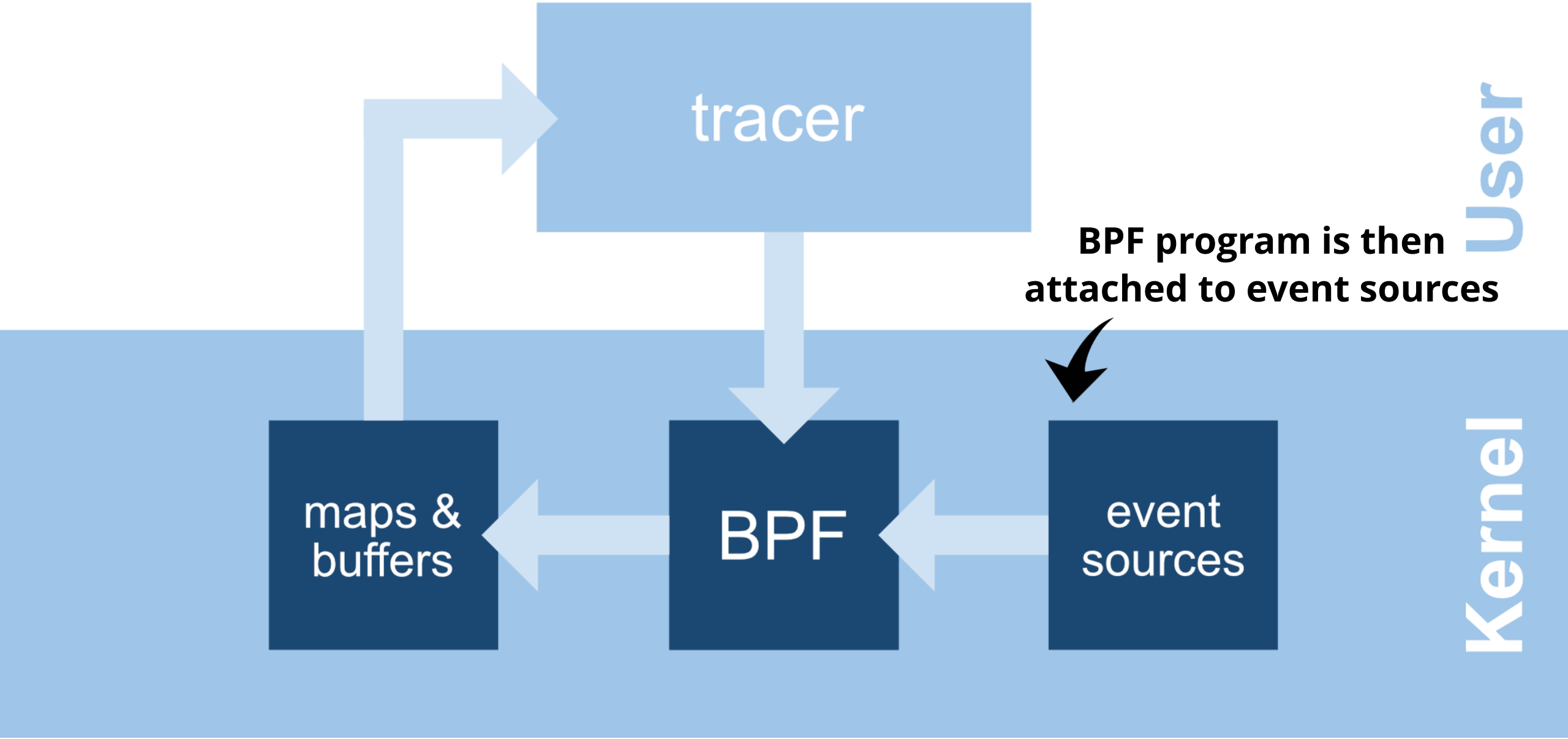
What is eBPF?

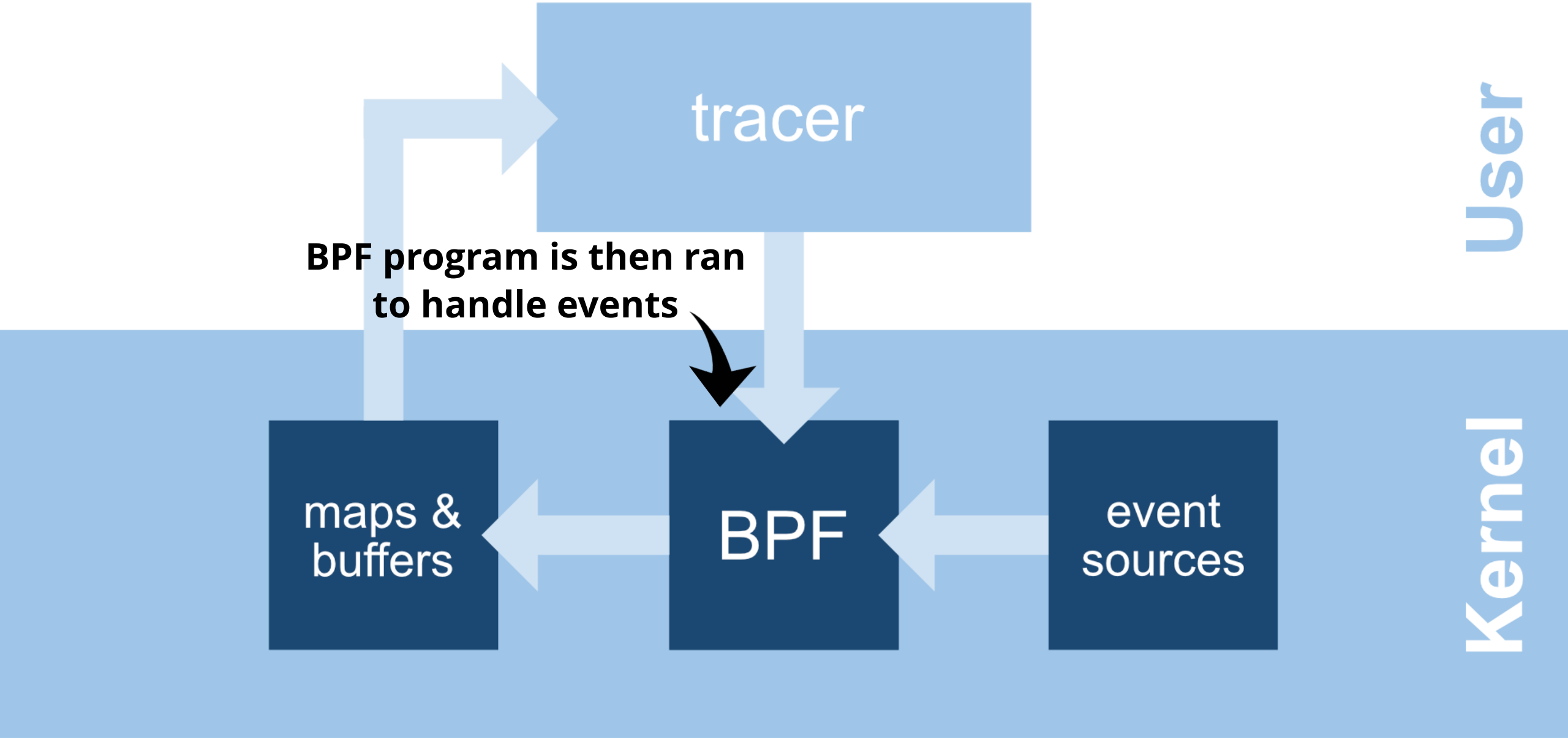
Starting with Linux 3.15 BPF has been incrementally enhanced to do **amazing things!**

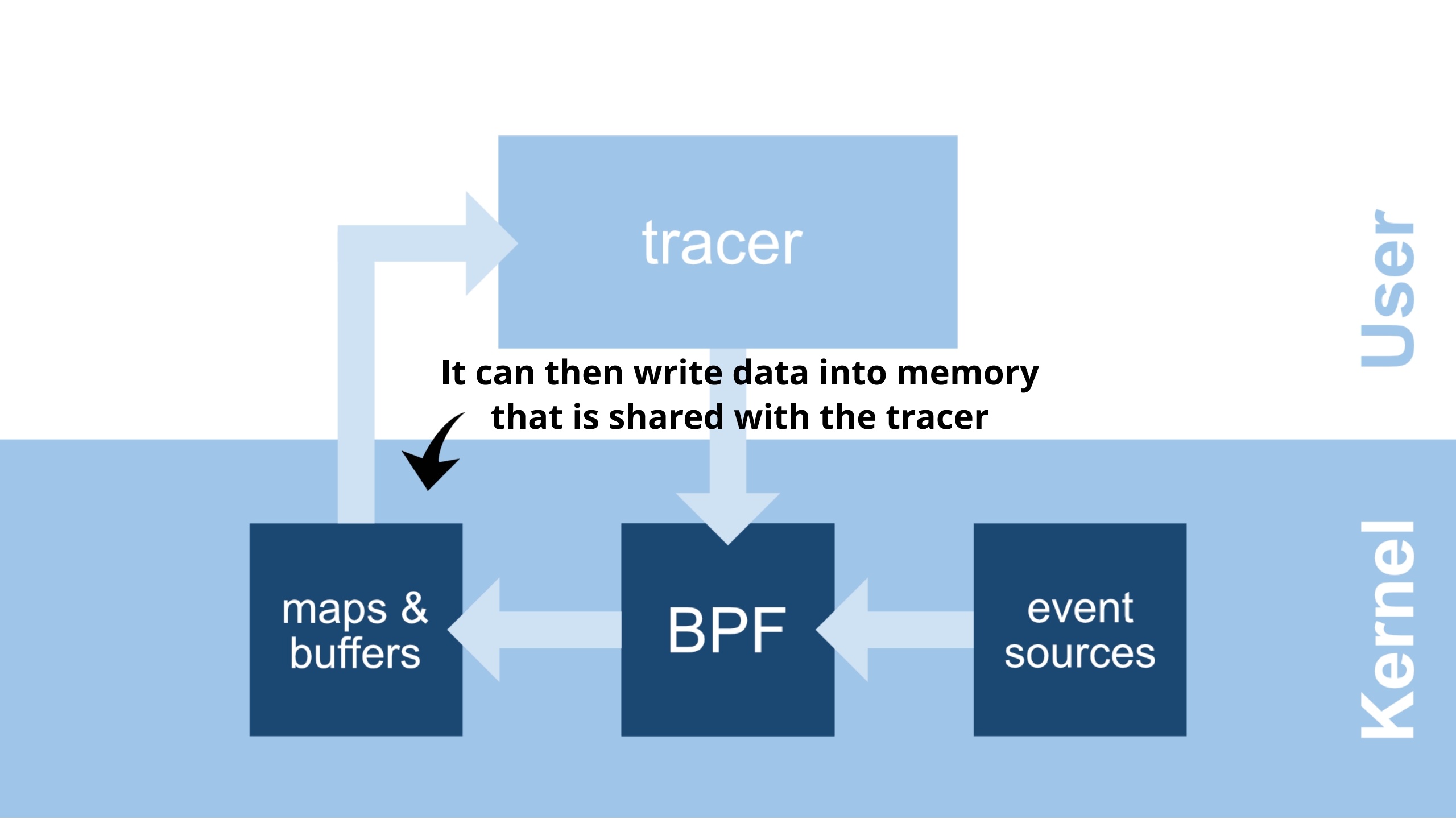
It is now used for tracing, security, networking, and monitoring!


tracer
User
maps &
buffers
BPF
event
sources
Kernel


tracer
BPF program is loaded,
verified, and compiled
to native code
User
maps &
buffers
BPF
event
sources
Kernel


tracer
BPF program is then
attached to event sources
User
maps &
buffers
BPF
event
sources
Kernel


tracer
BPF program is then ran
to handle events
maps &
buffers
BPF
event
sources
User
Kernel


tracer
It can then write data into memory
that is shared with the tracer
maps &
buffers
BPF
event
sources
User
Kernel

What can your BPF program do?

- Arithmetic/Logic/Branching
- Load/Store (restricted)
- Call user defined bpf functions
- Call various helper functions
  - Aggregate and store data in maps
  - Read stack traces for kernel and user land
  - Manipulate packets
  - Get time/rand data/current pid/task/etc
  - Read/write to certain places in memory
  - Much more!

What can your BPF program not do?

- No illegal instructions
- Your program must have a finite execution
- Loops are not allowed
  - You can jump forward
  - You can jump back if it does not form loop
  - Bounded loops might be allowed in the future so you do not have to manually unroll loops
- Access to locks is not permitted (might be allowed in the future)
- Access to arbitrary memory is not permitted
  - You can load/store the memory of the BPF program and access memory in other ways
- Unreachable blocks are not allowed

Event Sources

User Space

- uprobes - dynamic
- usdt - static (uses uprobes)

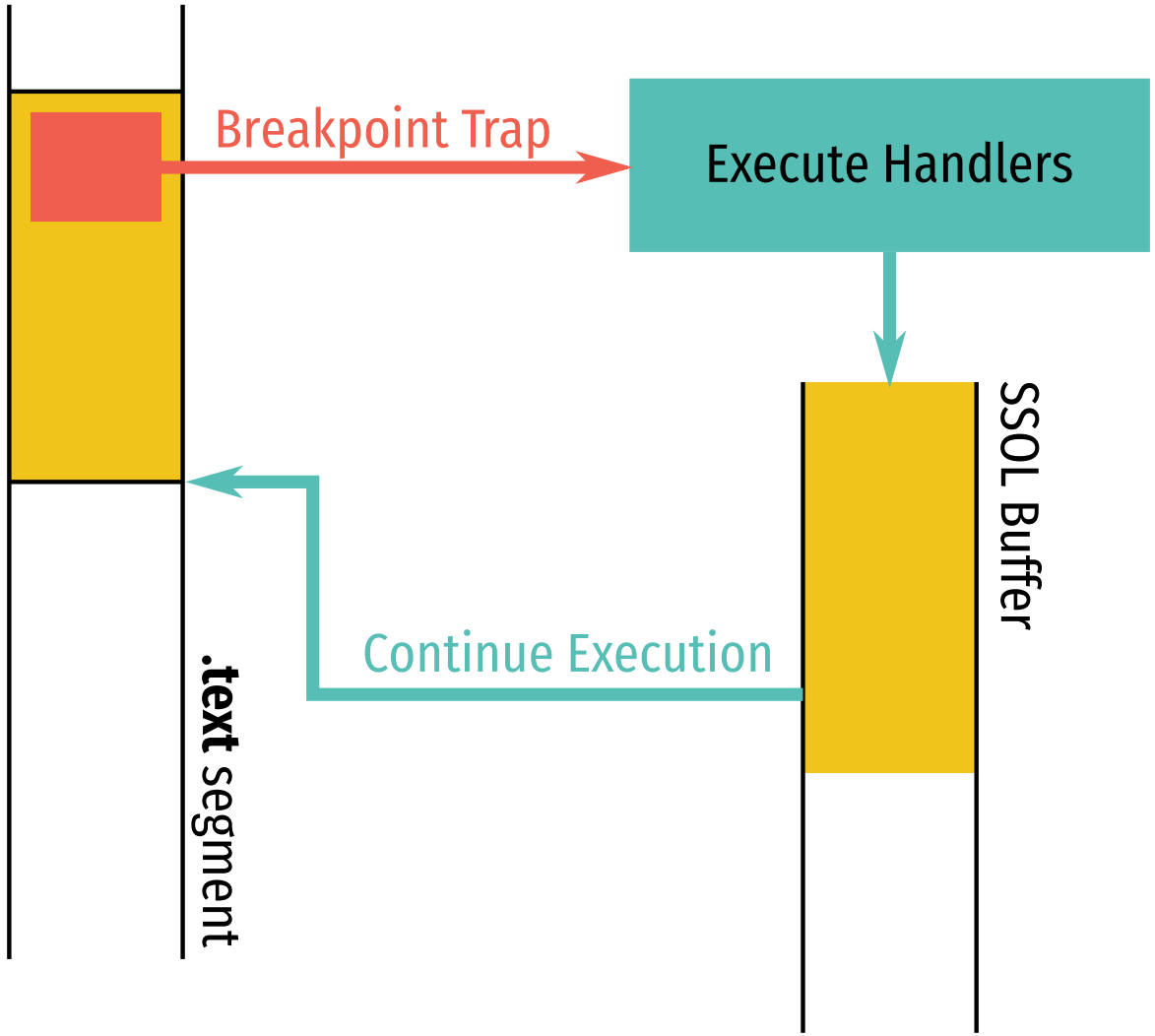
Kernel

- kprobes - dynamic
- tracepoints - static

Other

- sockets
- tc
- perf events
- etc

uprobes allows you to trace any instruction in user land with much **less overhead** than ptrace


Breakpoint Trap
Execute Handlers
SSOL Buffer
Continue Execution
.text segment

USDT

- Tracepoints that are statically defined by the developer
- They are typically used as tracing landmarks that are stable across time
- Can report arbitrary data when they fire
  - Kind of like logging but without always paying the performance cost
- Supported in most language runtimes (Java, Python, Node, Ruby)
  - This allows you to trace functions in dynamic languages by attaching to probes such as function__entry and function__return.
- Implemented in linux using uprobes

So, how do you write BPF programs?

What, you don't want to write the machine code?

BCC

github.com/iovisor/bcc

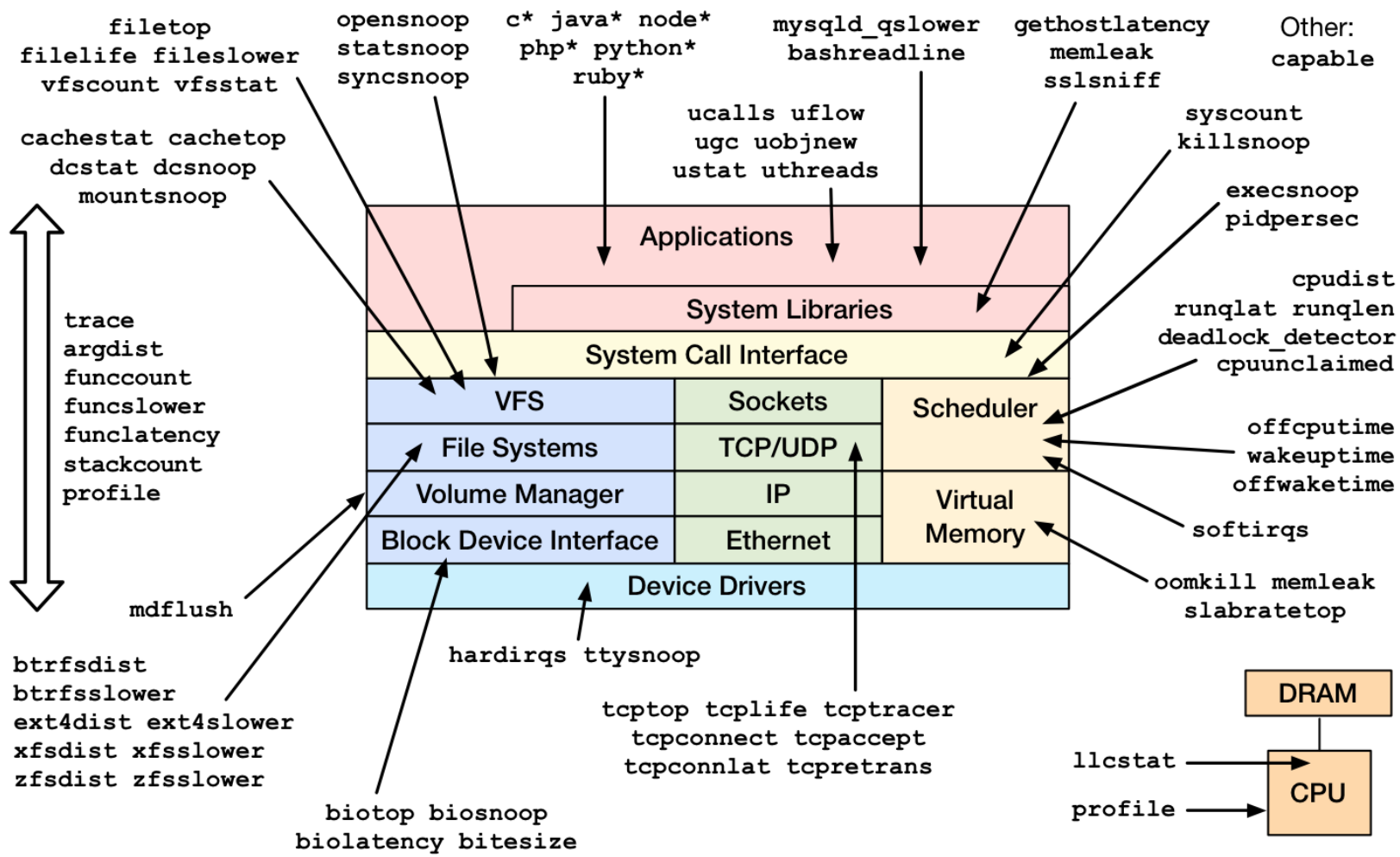
bpftrace

github.com/iovisor/bpftrace

BCC (BPF Compiler Collection)

- BCC is a compiler for BPF programs that are written in C
- It also assists with interacting with your BPF programs from user land
- It is implemented as a library (libbcc.so)
- This library has a lot of awesome functionality and is quite mature
- It comes with a collection of pre-built tools that are incredibly useful
- It also comes with bindings for Python and LUA
- Third party Go bindings exist

Linux bcc/BPF Tracing Tools



https://github.com/iovisor/bcc#tools 2017

```
func f() {
        atomic.AddUint64(&count, 1)
}

func reportCount() {
        for {
                n := atomic.SwapUint64(&count, 0)
                p.Printf("%15d ops/s\n", n)
                time.Sleep(time.Second)
        }
}

func main() {
        go reportCount()
        for {
                f()
        }
}
```

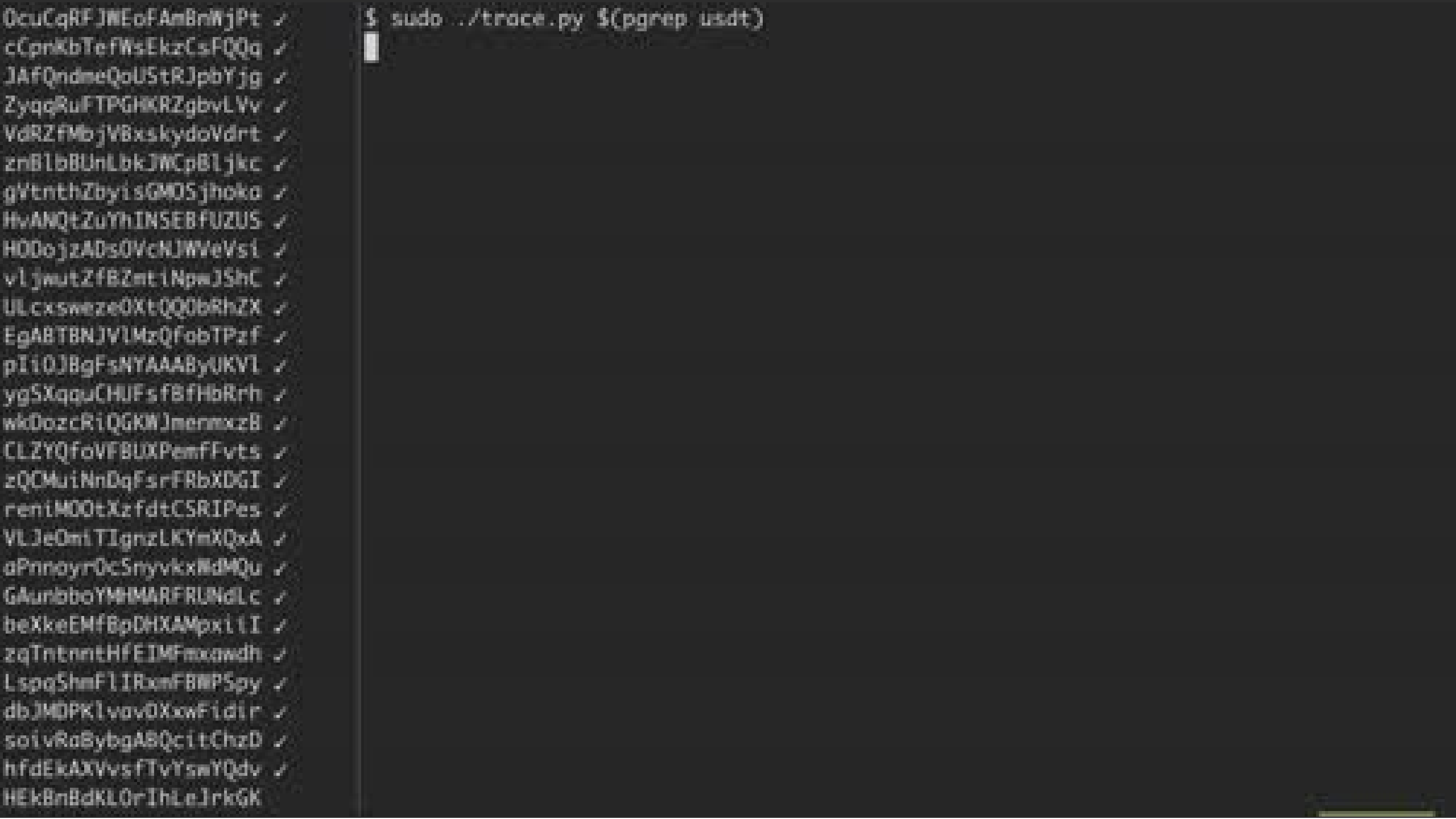
```
bpf_text = r"""
BPF_ARRAY(count, u64, 1);

int do_trace() {
    count.increment(0);
    return 0;
};
"""

b = BPF(text=bpf_text)
b.attach_uprobe(name=sys.argv[1], sym="main.f", fn_name="do_trace")

count = b["count"]

while True:
    time.sleep(1)
    print("{:15,} ops/s".format(count[0].value))
    count.clear()
```


$ uprobes
$ sudo ./trace.py $(which uprobes)

```
var (
        probes = salp.NewProvider("usdt")
        entry  = salp.MustAddProbe(probes, "entry")
        exit   = salp.MustAddProbe(probes, "exit")
)

func f() {
        entry.Fire()
        defer exit.Fire()
        http.Get("https://www.google.com/search?q=" + randStr())
}

func main() {
        salp.MustLoadProvider(probes)
        defer salp.UnloadAndDispose(probes)

        for {
                f()
        }
}
```

```
BPF_ARRAY(start, u64, 1);
BPF_HISTOGRAM(latency, u64);

int trace_entry() {
    u64 ts = bpf_ktime_get_ns();
    int zero = 0;
    start.update(&zero, &ts);

    return 0;
};

int trace_exit() {
    u64 *tsp;
    int zero = 0;

    // fetch timestamp and calculate delta
    tsp = start.lookup(&zero);
    if (tsp == 0 || *tsp == 0) return 0; // missed start
    u64 delta = (bpf_ktime_get_ns() - *tsp) / 1000000;

    // store as histogram
    latency.increment(bpf_log2(delta));
    start.delete(&zero);

    return 0;
};
```

```
u = USDT(pid=int(sys.argv[1]))
u.enable_probe(probe="entry", fn_name="trace_entry")
u.enable_probe(probe="exit", fn_name="trace_exit")
b = BPF(text=bpf_text, usdt_contexts=[u])

try:
    time.sleep(99999999)
except KeyboardInterrupt:
    b["latency"].print_log2_hist("milliseconds")
```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ULcxswezeOXtQQObRhZX ✓
EgABTBNJVlMzQfobTPzf ✓
pIiOJBgFsNYAAAByUKVl ✓
ygSXqquCHUFsfBfHbRrh ✓
wkDozcRiQGKWJmermxzB ✓
CLZYQfoVFBUXPemfFvts ✓
zQCMuiNnDqFsrFRbXDGI ✓
rentMOOtXzfdtCSRIPes ✓
VLJeOmiTIgnzLKYmXQxA ✓
aPnnoyrOcSnyvkxWdMQu ✓
GAunbboYMHMARFRUNdLc ✓
beXkeEMfBpDHXAMpxiiI ✓
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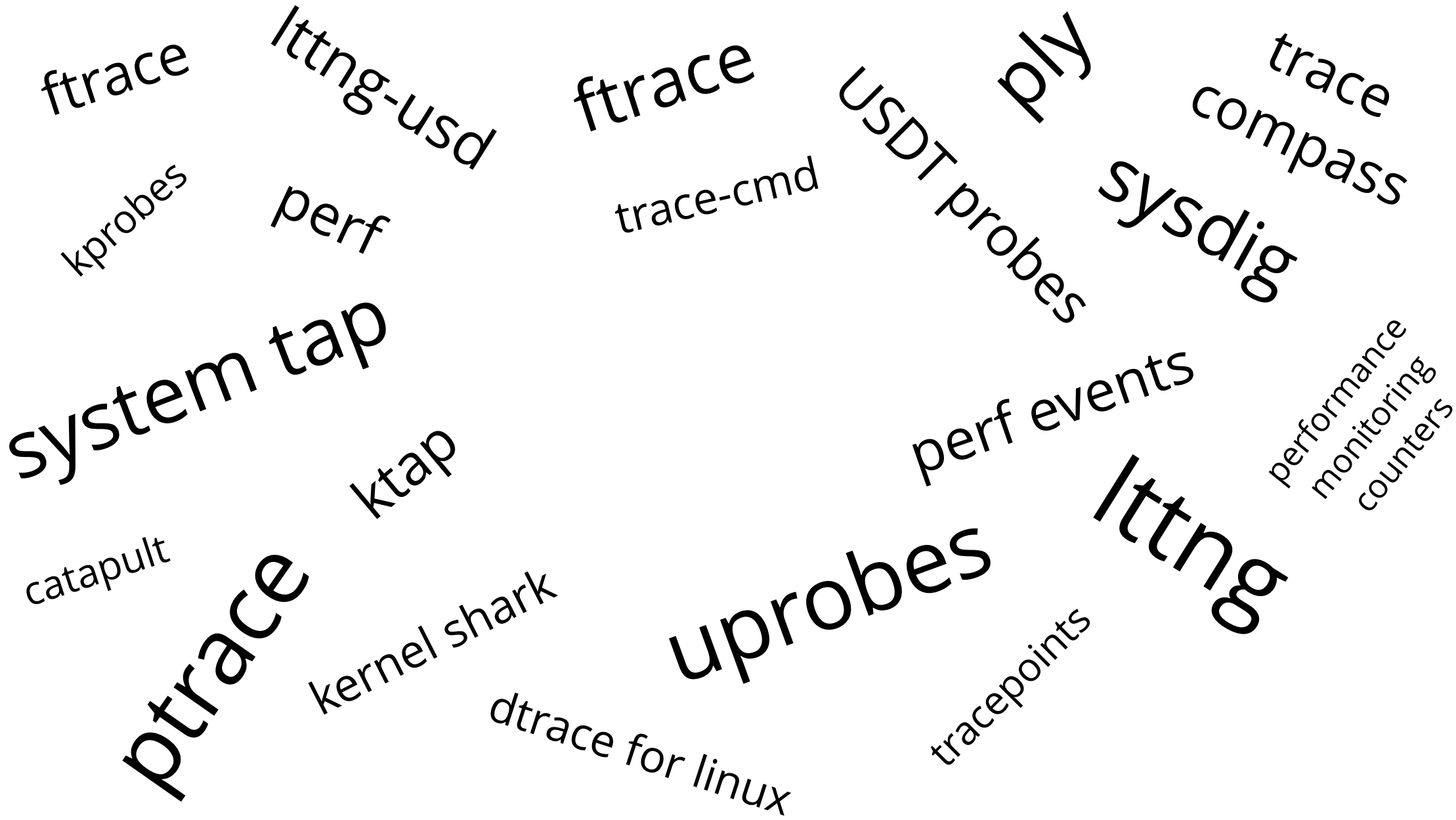
LspqShmFlIRxmFBWPSpy ✓
dbJMDPKlvavOXxwFidir ✓
soivRaBybgABQcitChzD ✓
hfdEkAXVvsfTvYswYQdv ✓
HEkBnBdKLOrIhLeJrkGK
$ sudo ./trace.py $(pgrep usdt)

bpftrace

simplifies writing these programs

```
// snoop on folks running bash

uretprobe:/bin/bash:readline {
    printf("readline: %s\n", str(retval));
}

// attach to used probe and print some args

usdt:/root/tick:loop {
    printf("%s: %d\n", str(arg0), arg1);
}

// calculate latency of read syscalls

tracepoint:syscalls:sys_enter_read {
    @start[tid] = nsecs;
}

tracepoint:syscalls:sys_exit_read / @start[tid] / {
    @times = hist(nsecs - @start[tid]);
    delete(@start[tid]);
}
```


ftrace
lttng-usd
ftrace
USDT probes
ply
trace compass
kprobes
perf
trace-cmd
sysdig
system tap
perf events
performance monitoring counters
ktap
catapult
ptrace
kernel shark
uprobes
lttng
tracepoints
dtrace for linux

BCC

github.com/iovisor/bcc

bpftrace

github.com/iovisor/bpftrace

docker

cgroups
namespaces
seccomp

bpftrace

ebpf
uprobes
kprobes
tracepoints
perf_events

- ✓ Intercepting at any point of execution
- ✓ Without restarting the process
- ✓ With as low overhead as possible
- ✓ Read and write to memory and registers
- ✓ Collect data across multiple processes and the kernel
- ✓ And do it all safely

Methods

Tools

Practice

We need to Deploy a Container to Probe our Applications

```
spec:
  # share host pid namespace
  hostPID: true
  containers:
  - name: towel
    image: jasonkeene/towel
    securityContext:
      # run as root
      privileged: true
    volumeMounts:
    - name: sys
      mountPath: /sys
    - name: libmodules
      mountPath: /lib/modules
    - name: varlibdocker
      mountPath: /var/lib/docker
    - name: varrun
      mountPath: /var/run
  volumes:
  # kernel/debug/tracing
  - name: sys
    hostPath:
      path: /sys

  # kernel headers
  - name: libmodules
    hostPath:
      path: /lib/modules

  # container file systems
  - name: varlibdocker
    hostPath:
      path: /var/lib/docker

  # docker.sock
  - name: varrun
    hostPath:
      path: /var/run
```

$

$

This runs as **root!**

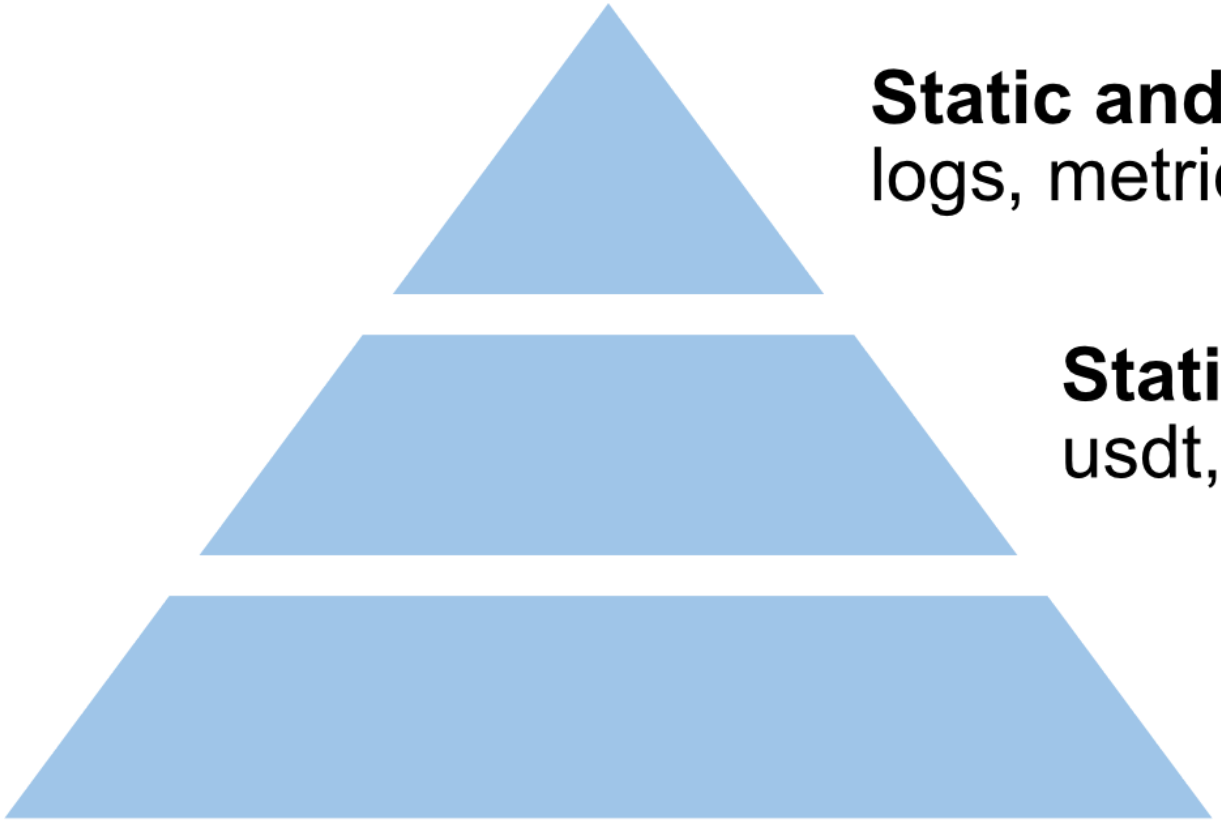
Make sure you delete the daemonset when it is no longer needed.

Also, put the daemonset in a namespace that is restricted.

```yaml
kind: Role
apiVersion: rbac.authorization.k8s.io/v1
metadata:
  namespace: secret-namespace
  name: exec-towel
rules:
# ...
- apiGroups: [""]
  resources: ["pods/exec"]
  verbs: ["create"]
```

```yaml
kind: RoleBinding
apiVersion: rbac.authorization.k8s.io/v1
metadata:
  namespace: secret-namespace
  name: jane-exec-towel
subjects:
- kind: User
  name: jane
  apiGroup: rbac.authorization.k8s.io
roleRef:
  kind: Role
  name: exec-towel
  apiGroup: rbac.authorization.k8s.io
```

Hierarchy of Instrumentation



Static and Always On
logs, metrics, distributed tracing

Static and Requires Activation
usdt, lttng-ust, tracepoints

Dynamic Instrumentation
uprobes, ptrace, kprobes

Measurement Coverage

How to Get Started

github.com/jasonkeene/k8s-towel

With these tools we can

Ask **Questions**, Get **Answers**

and

Better **Understand** our Systems

Thanks!

Jason Keene

Pivotal Software

github.com/jasonkeene