Signals and Timers

Introduction to Signals

- Signal
  - Notification to a process of an event
    - Interrupt whatever I was doing, and jump to signal handler
  - Enables Coordination of asynchronous events
    - Email message arrives on my machine
      - Mailing agent (user) process should retrieve it
    - Invalid memory access happens
      - OS should inform scheduler to remove process from the processor
    - Alarm clock goes off
      - Process which sets the alarm should catch it

Basic Signal Concepts

- Generation
  - The time the event that causes the signal occurs
- Delivery
  - The time when a process receives the signal
- Lifetime
  - The interval between generation and delivery
- Pending
  - A signal that is generated but not delivered
- Catch
  - A process catches a signal if it executes a signal handler when the signal is delivered
  - Alternatively, a process can ignore a signal when it is delivered
- Block
  - A process can temporarily prevent a signal from being delivered by blocking it
- Signal Mask
  - The set of signals currently blocked

Generating Signals

- Symbolic name
  - Starting with SIG
  - Signal names are defined in `<signal.h>`
- Users generated signals
  - e.g., `SIGUSR1`
- OS generated signals
  - e.g., `SIGSEGV` – invalid memory reference
- System call generated signals
  - e.g., `SIGALRM` – alarm

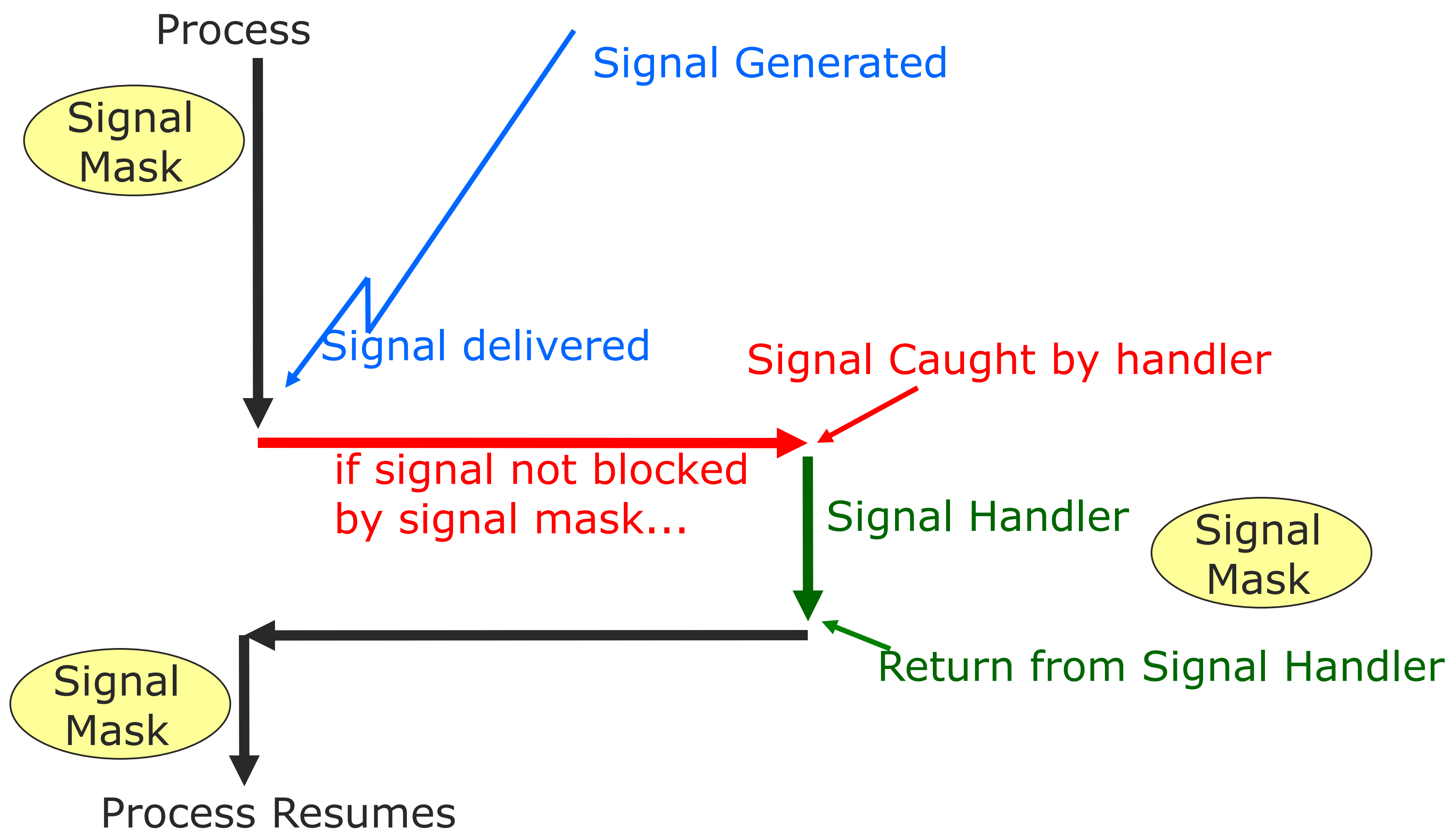
Some POSIX Required Signals

Signal	Description	Default action
SIGABRT	abort process	implementation dependent
SIGALRM	alarm clock	abnormal termination
SIGBUS	access undefined part of memory	implementation dependent
SIGCHLD	child terminated, stopped or continued	ignore
SIGILL	invalid hardware instruction	implementation dependent
SIGINT	interactive attention signal (usually ctrl-C)	abnormal termination
SIGKILL	terminated (cannot be caught or ignored)	abnormal termination

Some POSIX Required Signals

Signal	Description	Default action
SIGSEGV	Invalid memory reference	implementation dependent
SIGSTOP	Execution stopped	stop
SIGTERM	termination	Abnormal termination
SIGTSTP	Terminal stop	stop
SIGTTIN	Background process attempting read	stop
SIGTTOU	Background process attempting write	stop
SIGURG	High bandwidth data available on socket	ignore

How Signals Work

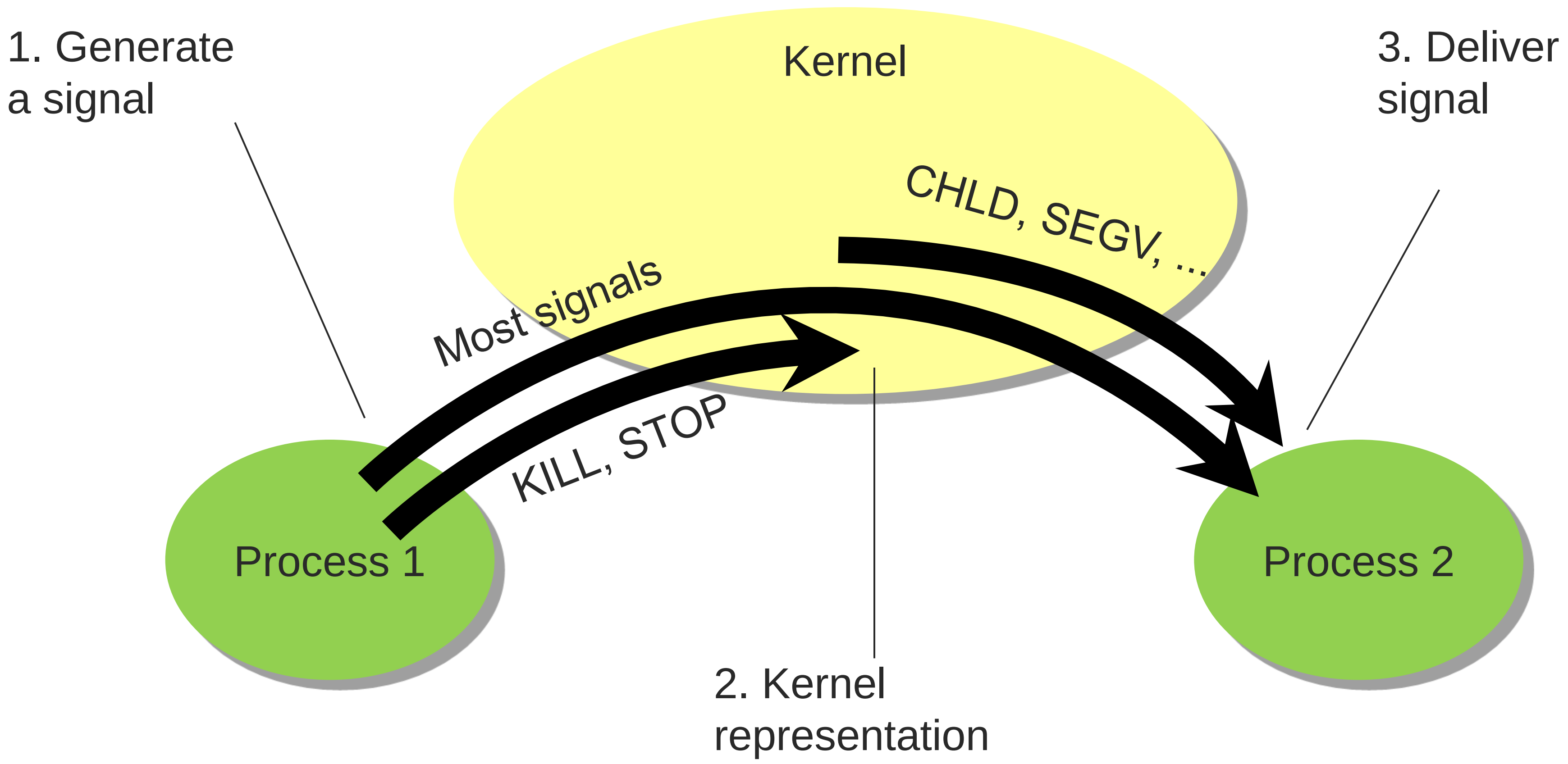


A little puzzle

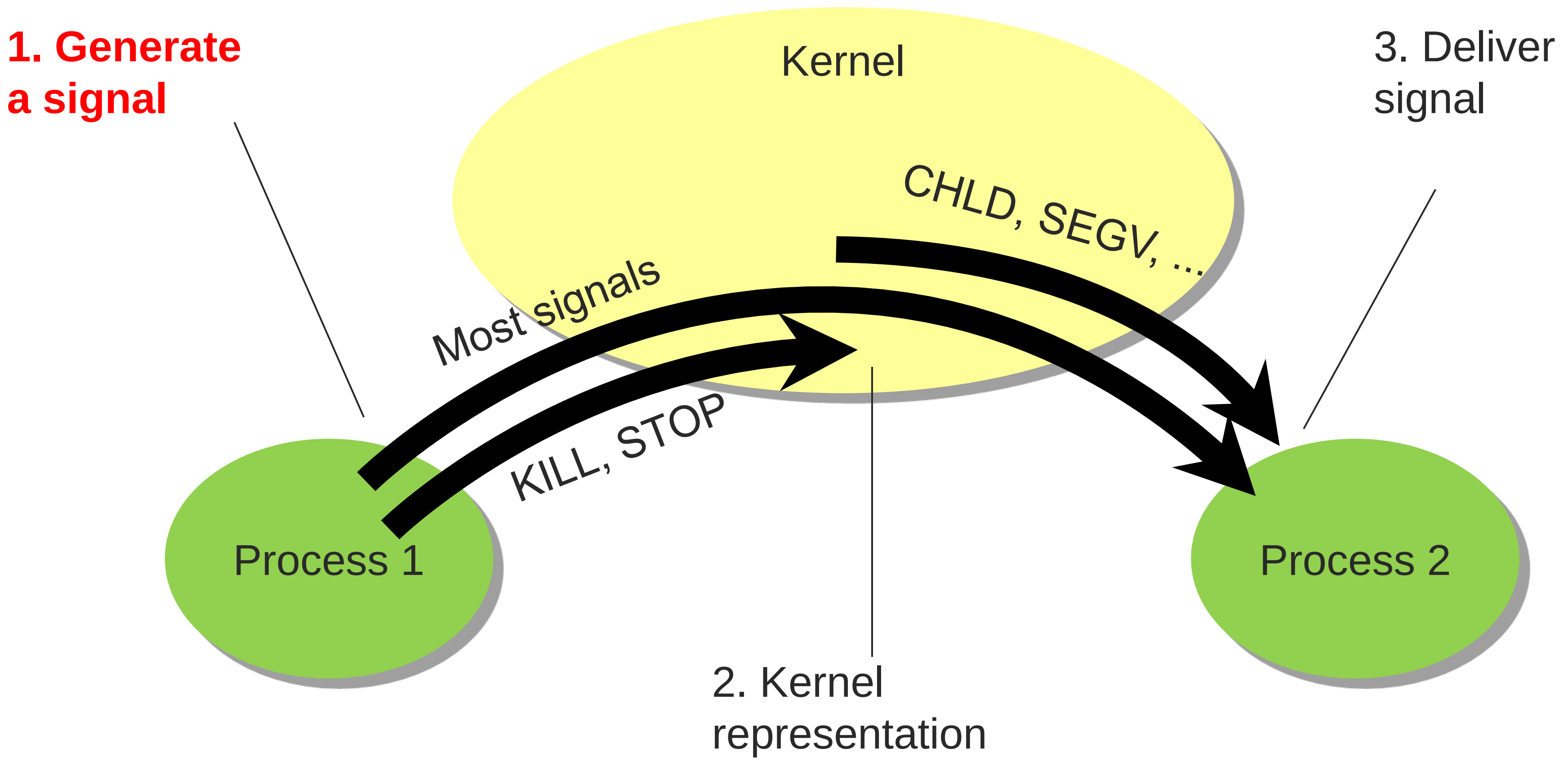
- Signals can be seen as a kind of interprocess communication
- What’s the difference between signals and, say, pipes or shared memory?
  - Asynchronous notification
  - Doesn’t send a “message” as such; just a signal number
  - Puzzle: Then how could I do *this*?

Run demo

Signaling


1. Generate a signal
Kernel
3. Deliver signal
CHLD, SEGV, ...
Most signals
KILL, STOP
Process 1
Process 2
2. Kernel representation

Signaling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Generating a signal

- Generated by a process
  - System call `kill(pid, signal)`
    - Sends `signal` to process `pid`
    - Poorly named: sends any signal, not just `SIGKILL`
- Generated by the kernel, when...
  - a child process exits or is stops (`SIGCHLD`)
  - floating point exception, e.g. div. by zero (`SIGFPE`)
  - bad memory access (`SIGSEGV`)
  - ...

Generating signals from the command line

- Signal a process from the command line
  - Use **`kill`**
  - **`kill -l`**
    - List the signals the system understands
  - **`kill [-signal] pid`**
    - Send signal to the process with ID **`pid`**.
    - Optional argument may be a name or a number (default is **`SIGTERM`**).
- To unconditionally kill a process
  - **`kill -9 pid`** which is the same as
  - **`kill -SIGKILL pid`**

Generating signals in interactive terminal applications

- **`CTRL-C`** is **`SIGINT`**
  - Interactive attention signal
- **`CTRL-Z`** is **`SIGSTOP`**
  - Execution stopped – cannot be ignored
- **`CTRL-Y`** is **`SIGCONT`**
  - Execution continued if stopped
- **`CTRL-\`** is **`SIGQUIT`**
  - Interactive termination: core dump

A program can signal itself

- Similar to raising an exception
  - `raise(signal)` or
  - `kill(getpid(), signal)`
- Or can signal after a delay
  - `unsigned alarm(unsigned seconds);`
  - Calls are not stacked
    - any previously set `alarm()` is cancelled
  - `alarm(20)`
    - Send `SIGALRM` to calling process after 20 seconds
  - `alarm(0)`
    - cancels current alarm

A program can signal itself

- Example: infinite loop ... for 10 seconds

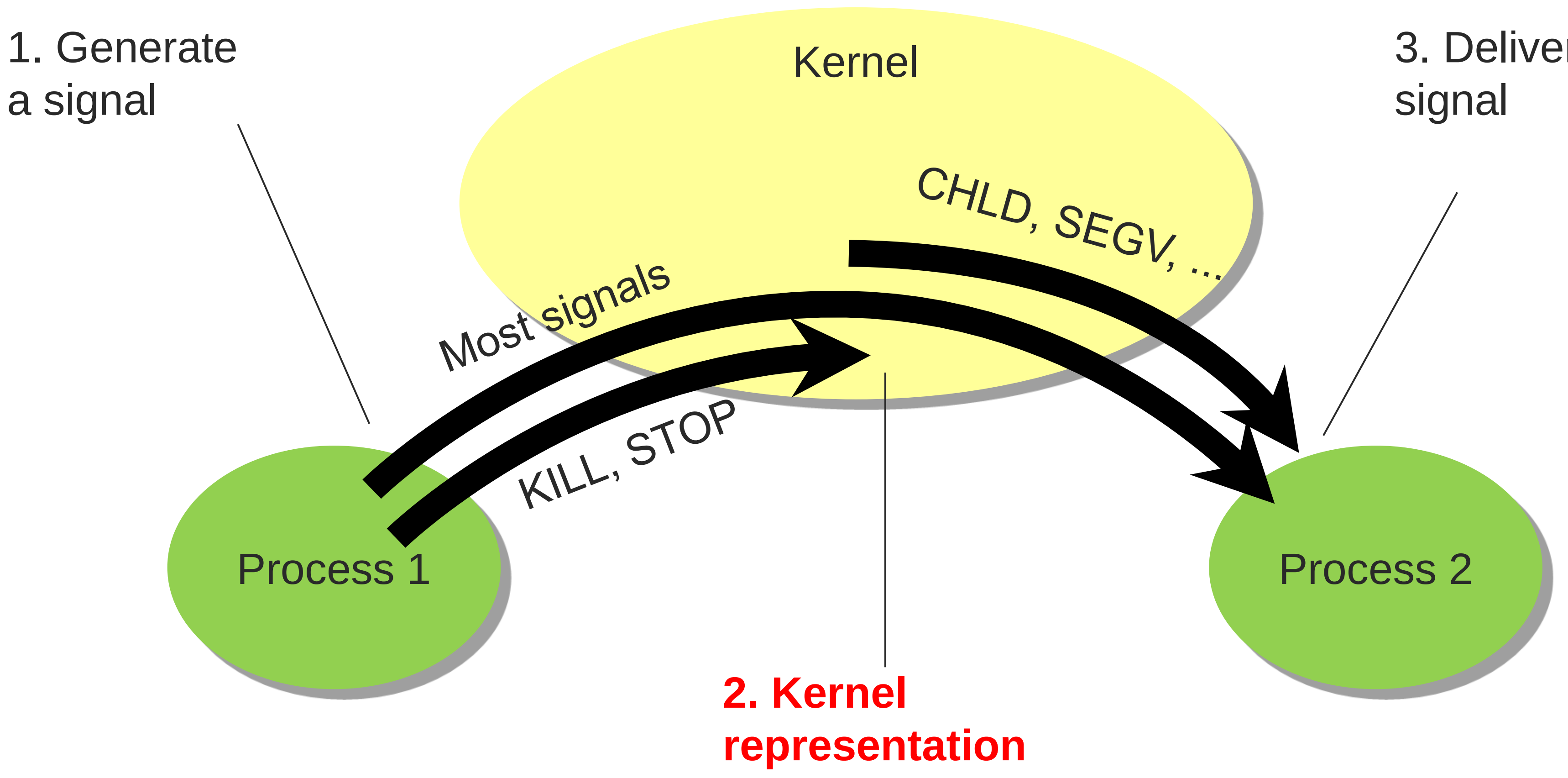
```
int main(void) {
   alarm(10);
   while(1);
}
```

Morbid example

```
#include <stdlib.h>
#include <signal.h>
int main(int argc, char** argv) {
    while (1) {
        if (fork())
            sleep(30);
        else
            kill(getppid(), SIGKILL);
    }
}
```

- What does this do?

Signaling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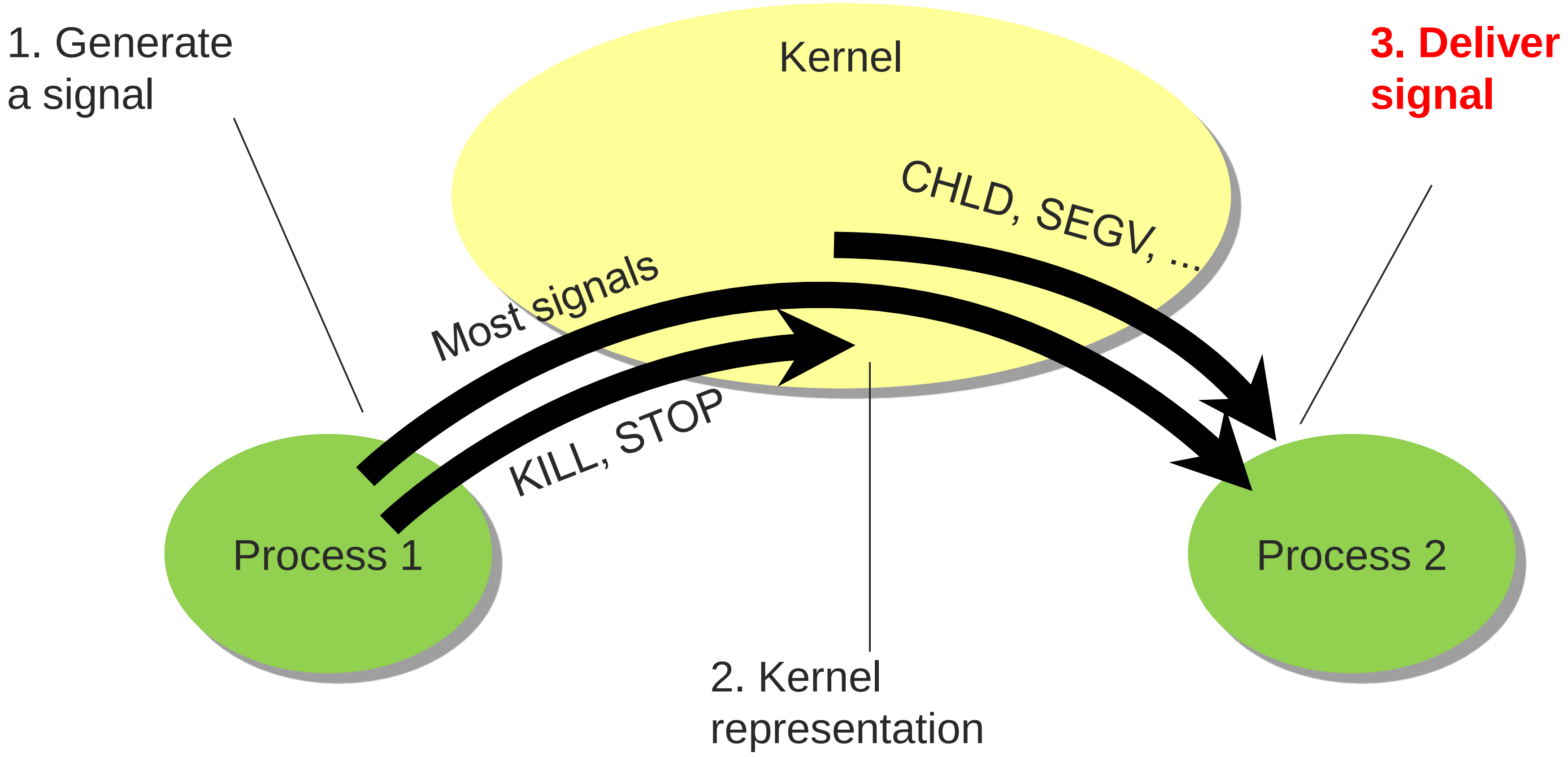
Kernel representation

- A signal is related to a specific process
- In the process's PCB, kernel stores
  - Set of pending signals
    - Generated but not yet delivered
  - Set of blocked signals
    - Will stay pending
    - Delivered after unblocked (if ever)
  - An action for each signal type
    - What to do to deliver the signal

Kernel signaling procedure

- Signal arrives
  - Set pending bit for this signal
    - Only one bit per signal type!
- Ready to be delivered
  - Pick a pending, non-blocked signal and execute the associated action–one of:
    - Ignore
    - Kill process
    - Execute signal handler specified by process

Signaling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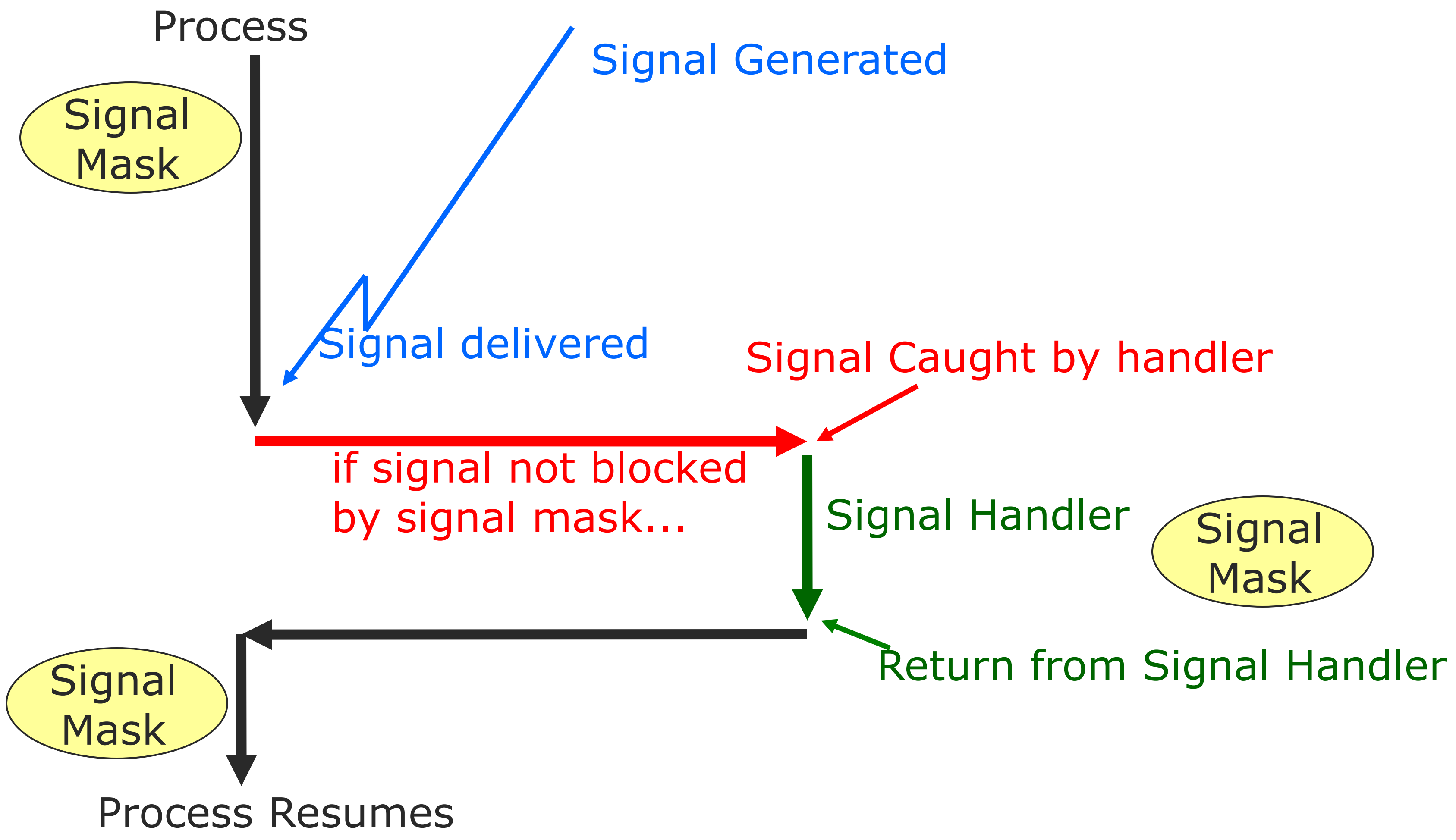
Delivering a signal

- Kernel may handle it
  - `SIGSTOP`, `SIGKILL`
  - Target process can’t handle these
  - They are really messages to the kernel **about** a process, rather than **to** a process
- For most signals, target process handles it (if it wants)

If process handles the signal...



Signal mask

- Temporarily prevents select types of signals from being delivered
  - Implemented as a bit array
  - Same as kernel’s representation of pending and blocked signals

SigInt	SigQuit	SigKill	…	SigCont	SigAbrt
1	0	1	…	1	0

Signal mask example

- Block all signals

```
sigset_t sigs;
sigfillset(&sigs);
sigprocmask(SIG_SETMASK, &sigs,
    NULL);
```

- See also
  - **sigemptyset**, **sigaddset**, **sigdelset**, **sigismember**

If it’s not masked, we handle it

- Three ways to handle
  - Ignore it
    - Different than blocking!
  - Kill process
  - Run specified signal handler function
- One of these is the default
  - Depends on signal type
- Tell the kernel what we want to do: `signal()` or `sigaction()`

sigaction

```
#include <signal.h>
int sigaction(int signum, const struct sigaction
    *act, struct sigaction *oldact);
```

- Change the action taken by a process on receipt of a specific signal
- Notes
  - Any valid signal except `SIGKILL` and `SIGSTOP`
  - If `act` is non-null, new action is installed from `act`
  - If `oldact` is non-null, previous action is saved in `oldact`
  - Any

Example: Catch control-c

```
#include <stdio.h>
#include <signal.h>

void handle(int sig) {
   char handmsg[] = "Ha! Blocked!\n";
   int msglen = sizeof(handmsg);
   write(2, handmsg, msglen);
}
```

Example: Catch control-c

```
int main(int argc, char** argv) {
   struct sigaction sa;
   sa.sa_handler = handle;
   sa.sa_flags = 0;

   sigemptyset(&sa.sa_mask);
   sigaction(SIGINT, &sa, NULL);
   while (1) {
      printf("Fish.\n");
      sleep(1);
   }
}
```

Note: Need to check for error conditions in all these system & library calls!

Run demo

Potentially unexpected behavior

- Only one pending signal of each type at a time
  - If another arrives, it is lost
- What's an interesting thing that could happen during a signal handler?
  - Another signal arrives!
  - Need to either
    - Write code that does not assume mutual exclusion (man `sigaction`), or
    - Block signals during signal handler (`signal()` and `sigaction()` can do this for you)

How to catch without catching

- Can wait for a signal
  - No longer an asynchronous event, so no handler!
- First block all signals
- Then call `sigsuspend()` or `sigwait()`
  - Atomically unblocks signals and waits until signal occurs
  - Looks a lot like condition variables, eh?

And now back to the puzzle...

- Can we support arbitrary communication between processes using only signals?
- Idea
  - Even with two signals, we can get 1 bit of information from receipt of a signal....