Self-propelled Instrumentation

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Paradyn Project

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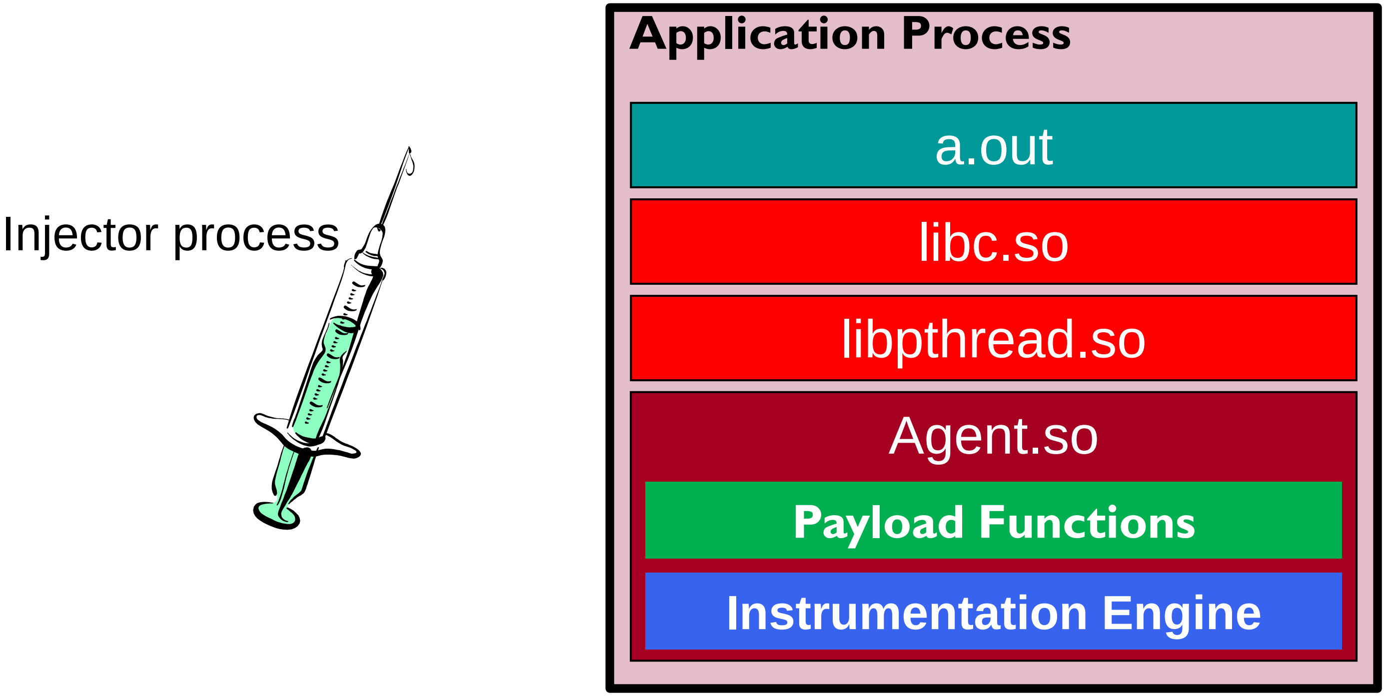
Overview

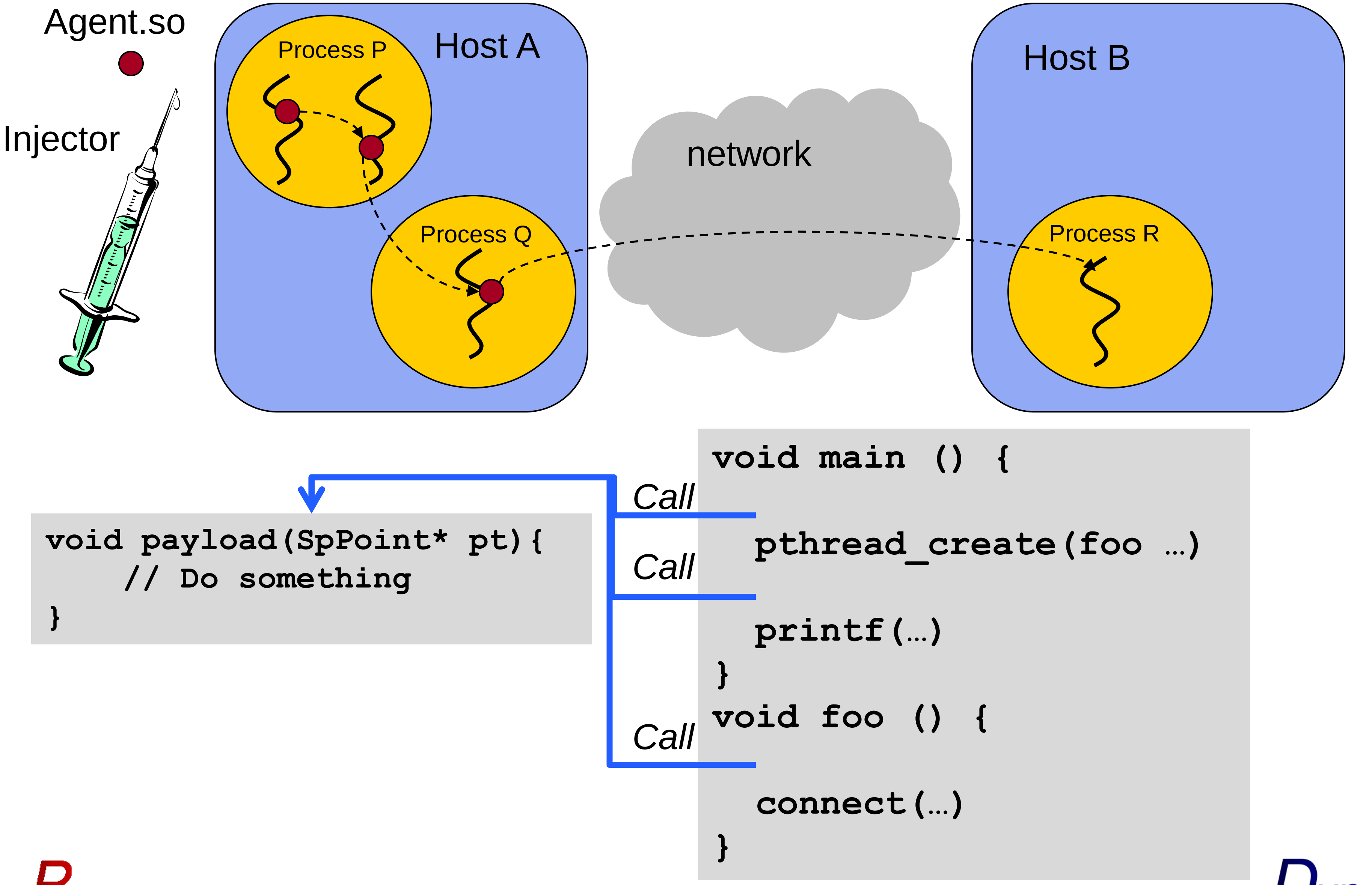
- Self-propelled instrumentation
  - Inject a fragment of code into the target process
  - Instrumentation automatically follows control flow
    - Within process
    - Cross process / host boundary
- Features
  - 1st party execution in the same address space
  - On demand, function call level instrumentation
- Applications
  - Fault diagnosis, security analysis, …

Big Picture



- Injector: Process to inject shared library
- Agent: Shared library
  - User-specified payload functions
  - Instrumentation engine

How it works



```
void payload(SpPoint* pt){
    // Do something
}
```

```
void main () {

  pthread_create(foo …)

  printf(…)
}
void foo () {

  connect(…)
}
```

Reincarnation

Previous life (2006)

- Parallel implementation with Dyninst
- x86 Linux
- For research on fault diagnosis [1]

Reincarnation (2012)

- Leverage Dyninst toolkits
- x86/x86_64 Linux
- Initially for security analysis, also for more applications

[1] Alexander Vladimirovich Mirgorodskiy, "Automated problem diagnosis in distributed systems", Doctoral dissertation, University of Wisconsin-Madison, Madison, WI, USA, 2006.

Injector

- Inject a shared library before a process executes
  - Use dynamic linking to load agent (LD_PRELOAD)

- Inject a shared library for a process in execution
  - Use Dyninst toolkit (ProcControlAPI)

Agent – Contents

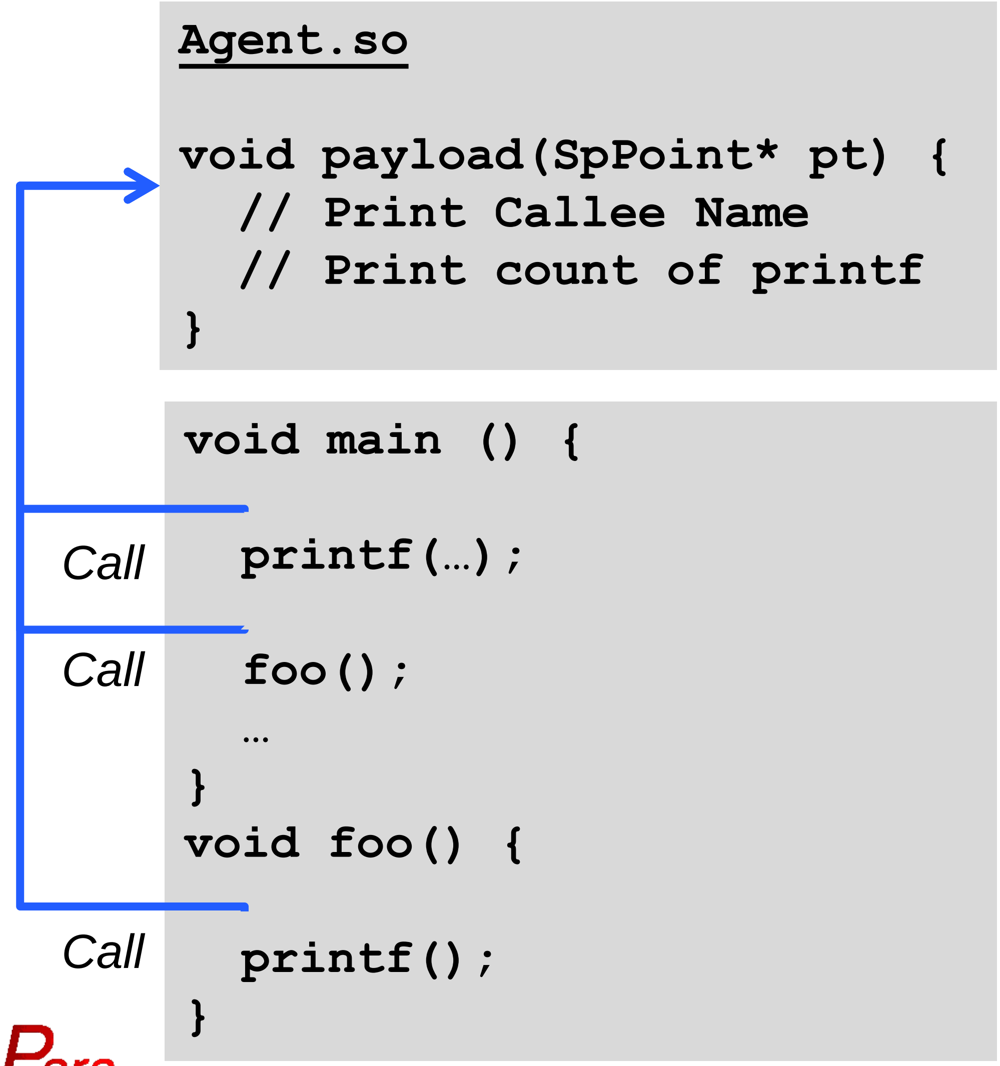
- User-provided payload functions
  - Entry payload: executed before each function call
  - Exit payload: executed after each function call

- Instrumentation Engine
  - Mainly based on PatchAPI
  - Also based on other Dyninst toolkits, e.g., Stackwalker, InstructionAPI, …

Agent – In payload function

- Query PatchAPI CFG structures
  - Functions / Basic blocks / Edges
  - Enables sophisticated code analysis
- Query runtime information related to the current function call
  - Arguments / Return value
- Detect system events
  - Communication events, e.g., send/recv
  - Security events, e.g., setuid

Example: Print func names and # of calls to printf



```
Agent.so

void payload(SpPoint* pt) {
  // Print Callee Name
  // Print count of printf
}
```

```
void main () {

  printf(…);
  foo();
  …
}
void foo() {

  printf();
}
```

```
Output:

CALL: printf
# printf: 1

CALL: foo

CALL: printf
# printf: 2
```

Payload functions

Single-threaded, single process

```
int count = 0;


void payload(SpPoint* pt) {

 PatchFunction* f = Callee(pt);
 if (!f) return;
 string name = f->name();

 printf(“CALL:%s\n”,name.c_str());

 if (name.compare(“printf”)==0){

  ++count;

  printf(“# printf: %d\n”,count);
 }

 Propel(pt);
}
```

Multi-threaded, single process

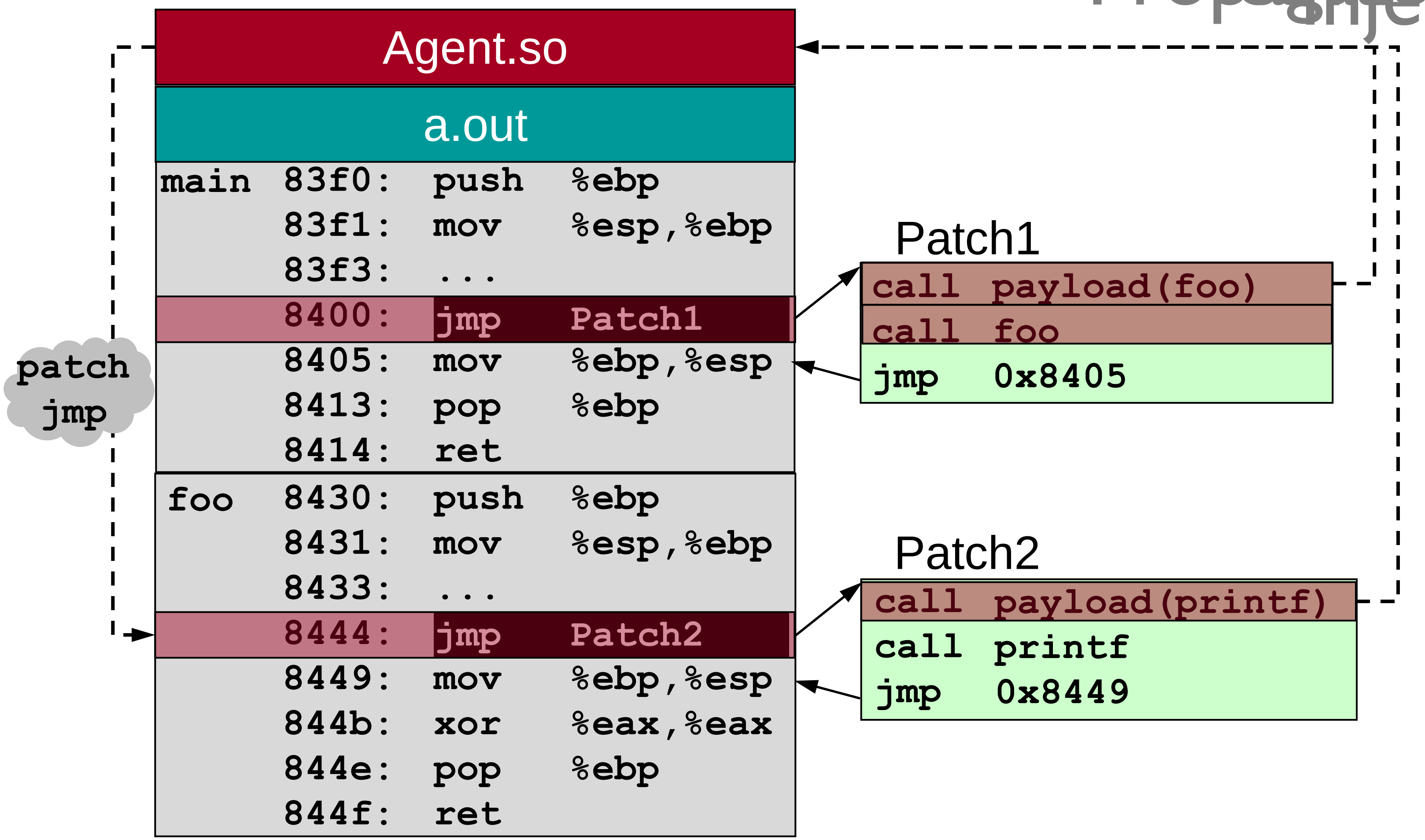
```
int count = 0;
SpLock count_lock = 0;

void payload(SpPoint* pt) {

 PatchFunction* f = Callee(pt);
 if (!f) return;
 string name = f->name();

 printf(“CALL:%s\n”,name.c_str());

 if (name.compare(“printf”)==0){
  sp::Lock(&count_lock);
  ++count;
  sp::Unlock(&count_lock);
  printf(“# printf: %d\n”,count);
 }

 Propel(pt);
}
```

Intra-process propagation

Propagate

Activate

Inject



Agent.so

a.out

```
main  83f0:  push  %ebp
      83f1:  mov   %esp,%ebp
      83f3:  ...
      8400:  jmp   Patch1
      8405:  mov   %ebp,%esp
      8413:  pop   %ebp
      8414:  ret
foo   8430:  push  %ebp
      8431:  mov   %esp,%ebp
      8433:  ...
      8444:  jmp   Patch2
      8449:  mov   %ebp,%esp
      844b:  xor   %eax,%eax
      844e:  pop   %ebp
      844f:  ret
```

Patch1

```
call  payload(foo)
call  foo
jmp   0x8405
```

Patch2

```
call  payload(printf)
call  printf
jmp   0x8449
```

Intra-process propagation challenges

- Instrumentation Engine
  - Call insn size < jump insn size
  - Call block size < jump insn size
  - Cannot find a suitable springboard

Relocate call block

Find springboard block

Use trap or ignore

Example: Print remote process name

Host 1 - 192.168.0.2 : 5370

```
Agent.so

void payload(SpPoint* pt) {
   // Print remote process Name
}
```

```
void main () {

  connect(…)
  recv(…)
  send(…)
}
```

Call payload

Output for 192.168.0.2:5370:

CONNECT: (192.168.0.2:5370, 192.168.0.31:8080)

READ FROM: 192.168.0.31:8080

WRITE TO: 192.168.0.31:8080

Host 2 - 192.168.0.31 : 8080

```
Agent.so

void payload(SpPoint* pt) {
   // Print remote process name
}
```

```
void main () {

  accept(…)
  send(…)
  recv(…)
}
```

Call payload

Output for 192.168.0.31:8080:

ACCEPT: (192.168.0.31:8080, 192.168.0.2:5370)

WRITE TO: 192.168.0.0.2:5370

READ FROM: 192.168.0.0.2:5370

Payload functions for IPC

```
void payload(SpPoint* pt) {
  PatchFunction* f = sp::Callee(pt);
  if (!f) return;

  if (IsConnect(f)) {
    fprintf(fp, “CONNECT: (%s, %s)\n”,
            LocalProcessName(),
            RemoteProcessName());
  } else if (IsIpcWrite(f)) {
   fprintf(fp, “WRITE TO: %s\n”,
            RemoteProcessName());
  } else if (IsIpcRead(f)) {
   fprintf(fp, “READ FROM: %s\n”,
            RemoteProcessName());
  }
  sp::Propel(pt);
}
```

Utilities

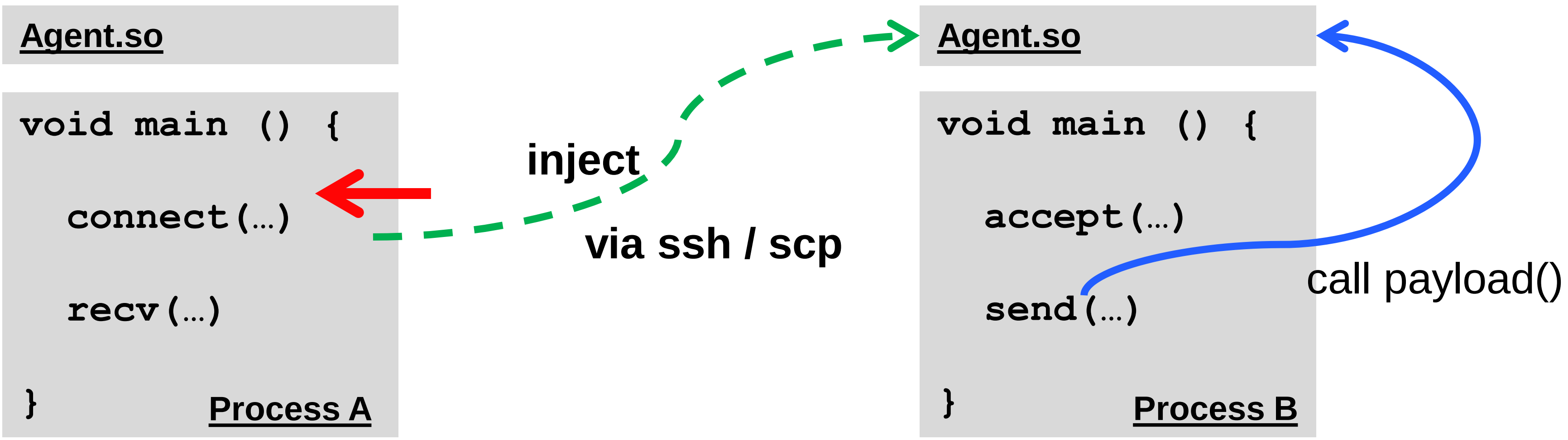
- Detect communication events.
- Get process name
  - e.g., 192.168.0.2:8080

IPC mechanisms

- Pipe
- TCP

Inter-process propagation

- Main procedure for inter-process propagation
  1. Detect the initiation of communication at the local site.
     - connect, write, send …
  2. Identify the remote process
  3. Inject the agent into the remote process
  4. Start following the flow of control in the remote site



Agent.so

```
void main () {
   connect(…)
   recv(…)
}
```

Process A

inject

via ssh / scp

Agent.so

```
void main () {
   accept(…)
   send(…)
}
```

Process B

call payload()

Applications

- Existing :
  - Fault diagnosis in distributed systems
  - Software security analysis
- Potential:
  - Error reporting in distributed systems
  - Performance profiling
  - Consistency analysis in distributed systems
  - Taint checking
  - More …

Status and Future work

- Status
  - x86 / x86_64 Linux
  - IPC: pipe, tcp
  - Testing and debugging to make it robust enough to work on complex programs, e.g., Google Chrome
- Future work
  - Develop tools for software security analysis
  - Support more protocols / mechanisms for inter-process propagation
  - Port to Microsoft Windows

Questions?