The Dyninst Binary Code Toolkits

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Walking Difficult Call Stacks

- Functions can produce call frames that are difficult to walk through
  - Optimize away frame pointers
  - Non-standard frame pointers
  - Regions where frame pointer is not yet set up
- New features in StackwalkerAPI
  - Use debug information from binary
  - Use static analysis on binary
  - Use heuristics to dynamically search call graph

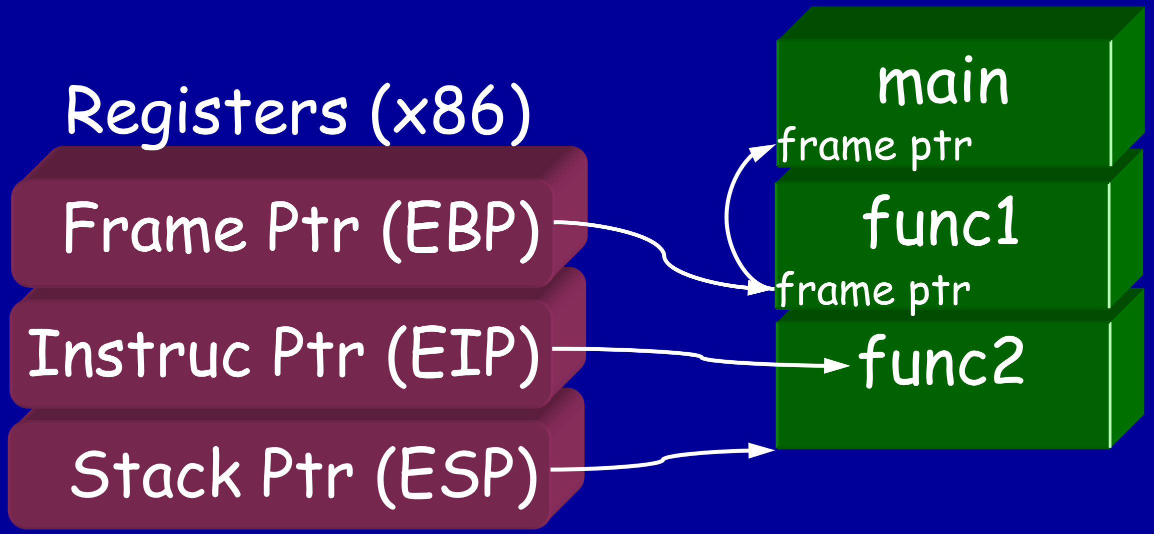
StackwalkerAPI

- Simple interface for collecting call stacks

```
walker = new walker(pid);
walker->walkStack(...);
```

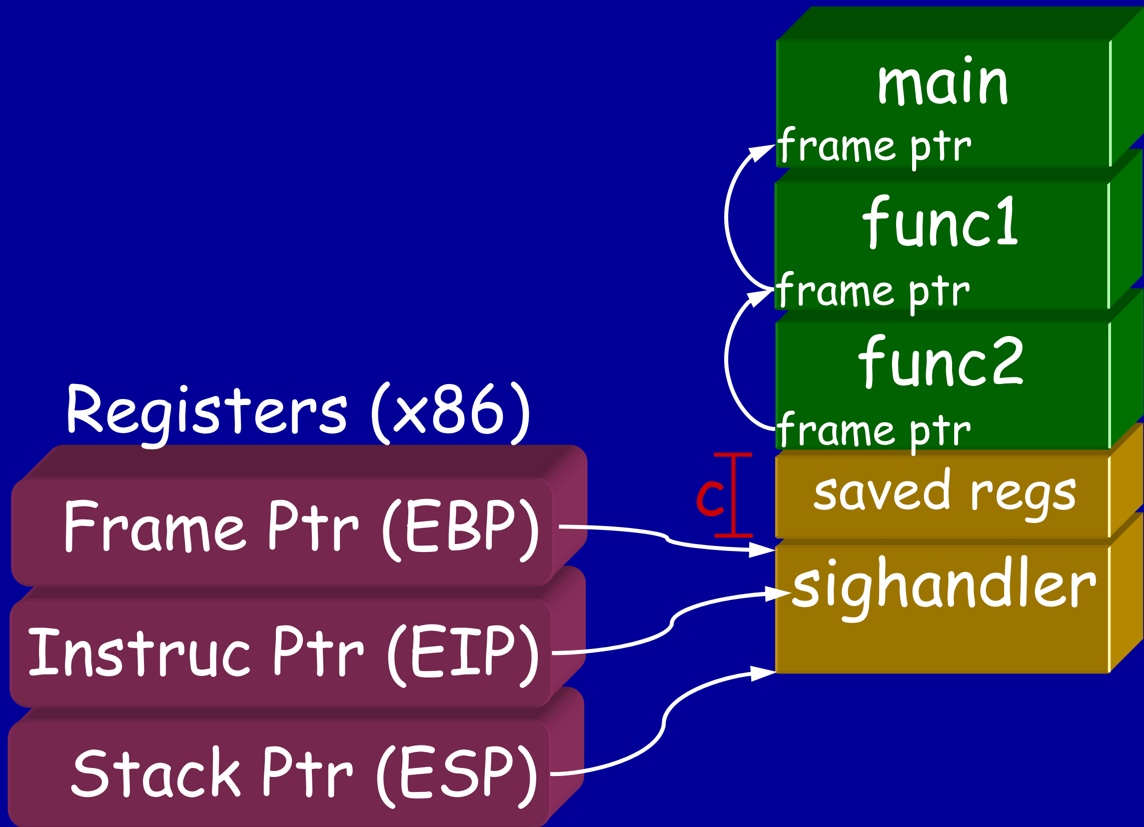
- Callback interface for customization
  - Walks through types of stack frames
  - Identifies types of stack frames
  - Looks up symbol names
  - Accesses target process

Easy Stackwalking



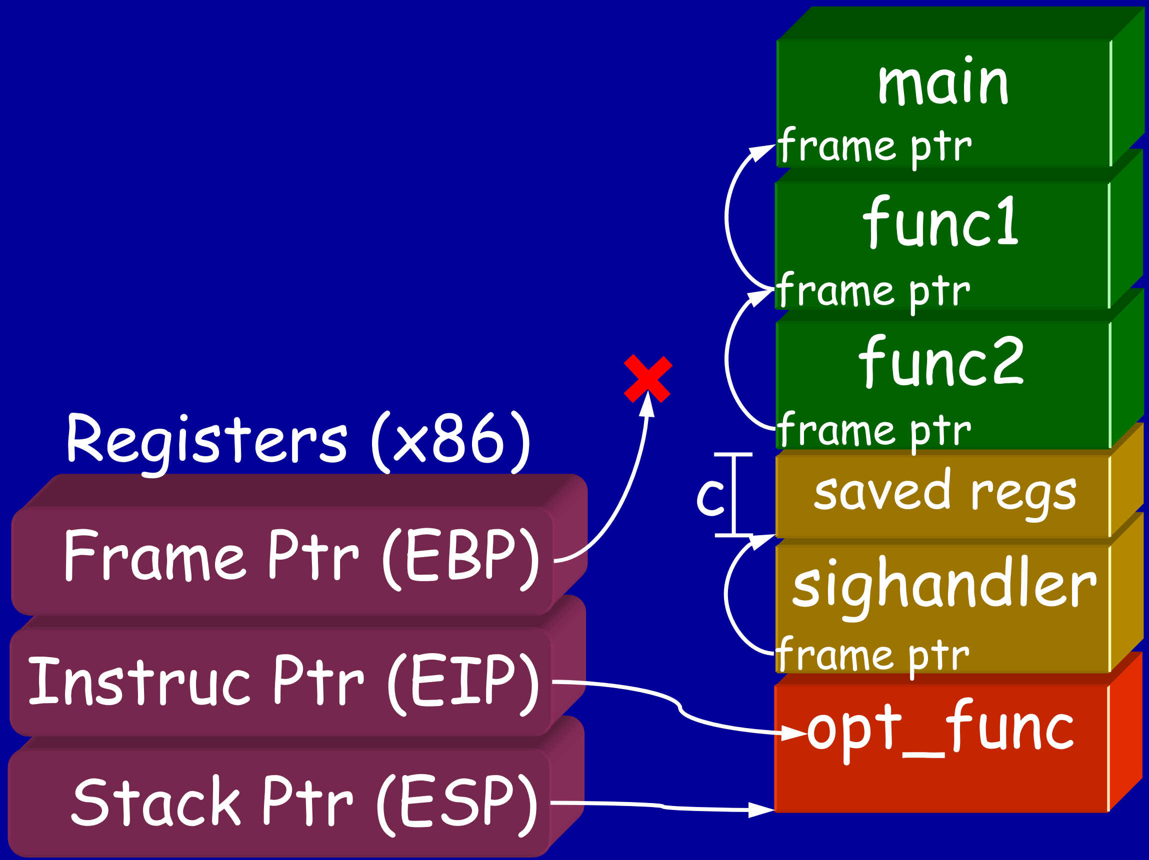
- Basic stack walking is essentially following a linked list.

~~Easy~~ Tricky Stackwalking



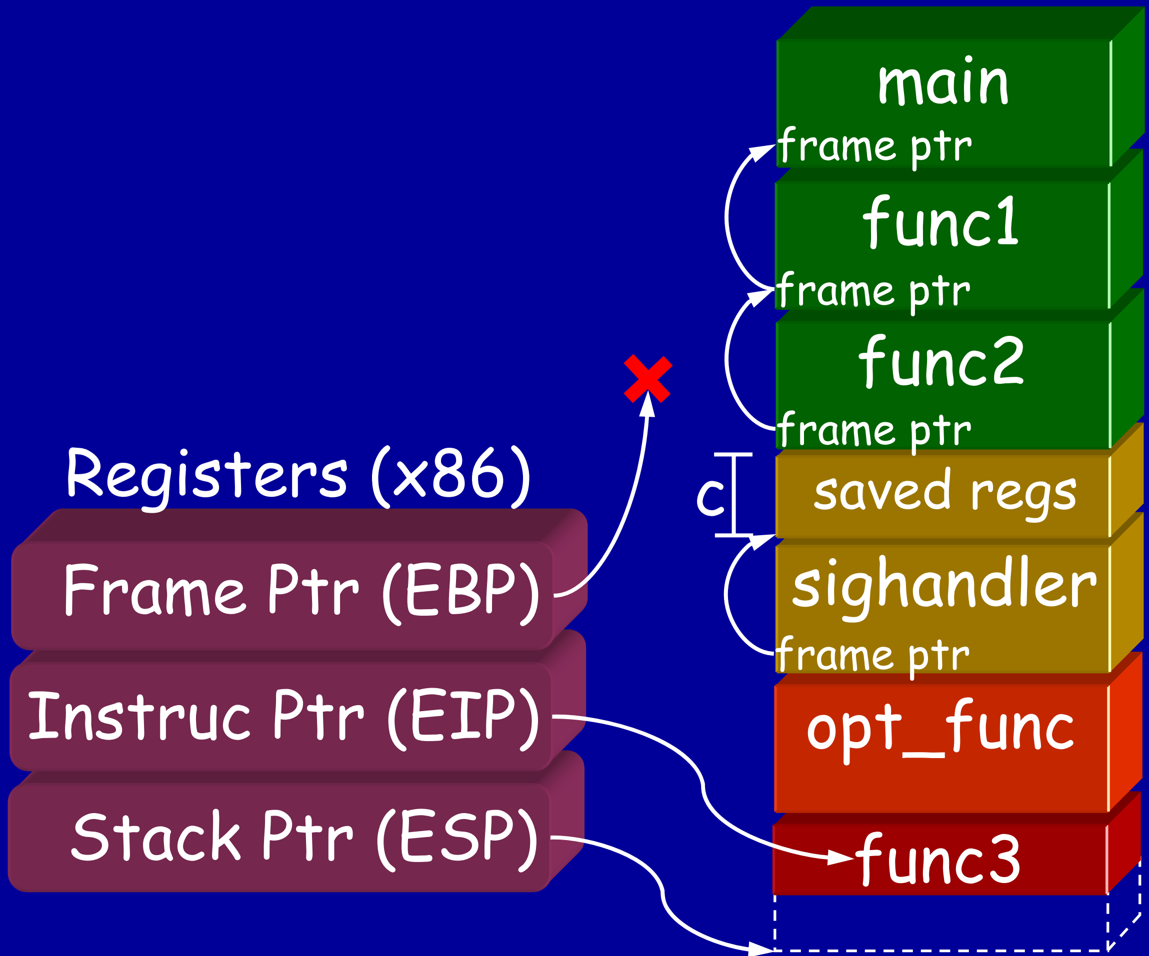
- Signal handlers and instrumentation tools may add non-standard frame layouts.

~~Easy~~ ~~Tricky~~ Difficult Stackwalking



- Optimized functions may trash frame pointers

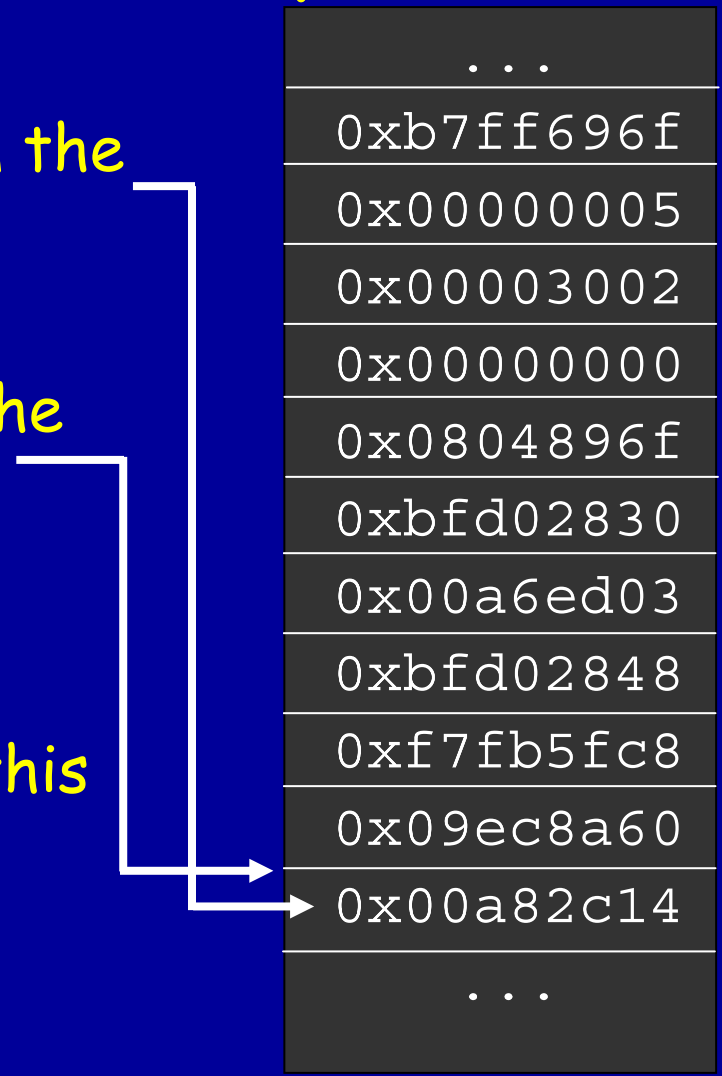
~~Easy~~ ~~Tricky~~ Very Difficult Stackwalking



- Functions may not yet have created stack frames, or could change stack frames during execution.

Stacks without frame pointers

- What we have
  - The return address from the previous frame.
  - A pointer to the top of the frame
- What we want
  - The return address for this frame



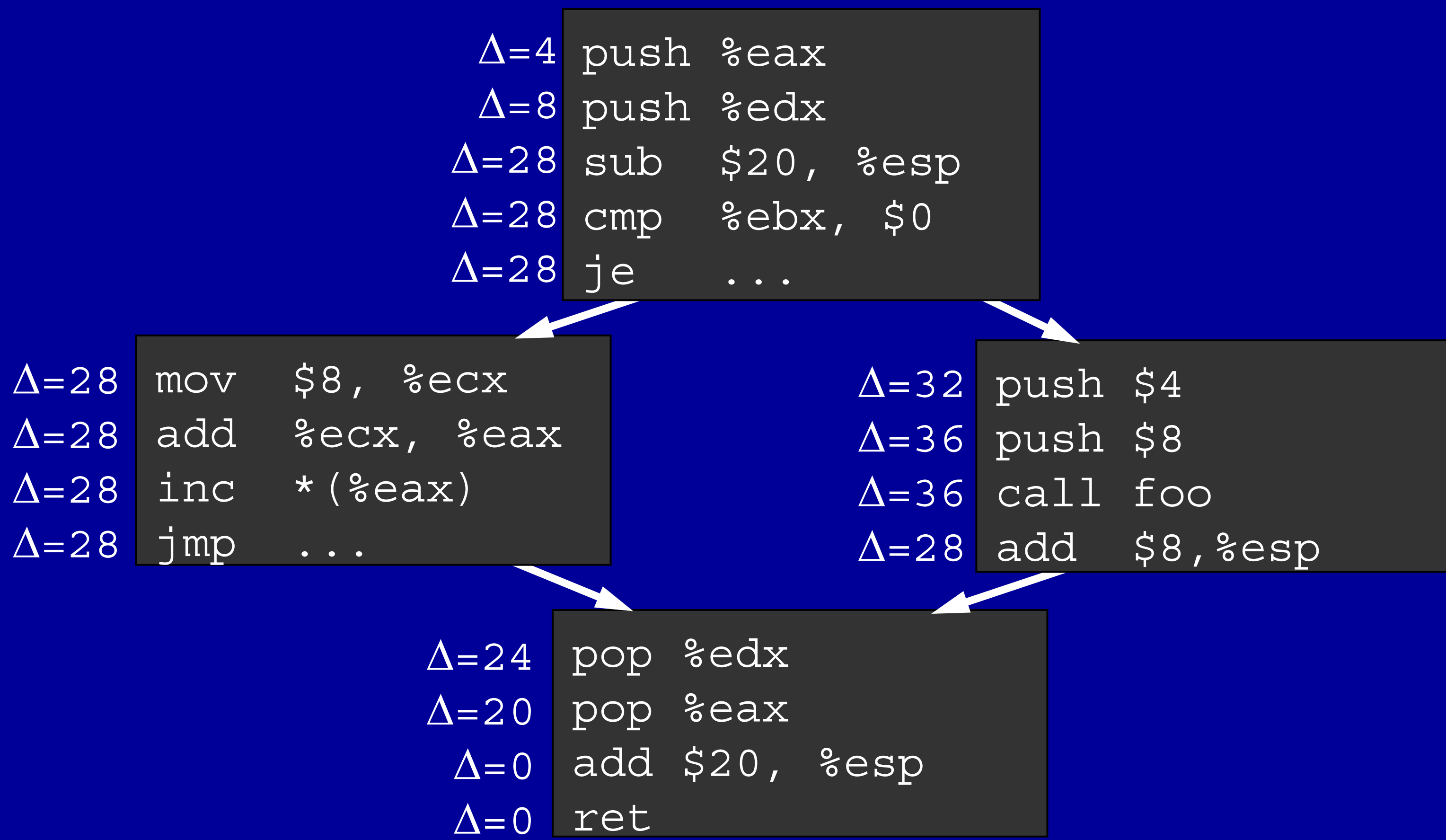
Techniques

- Debug Information
  - DWARF, STABS, etc… tell how to walk through a stack frame
- Static Analysis
  - Analyze the binary to understand what function stack frames look like
- Heuristic Stack Searching
  - Search through the stack to find stack frames

Debug Information

- Given a code address and process state gives the location of the return address.
    - E.g. the return address is 40 bytes above the top of the stack
    - E.g. the return address is at %ebp + 4
- Potential Issues
    - Is occasionally wrong
    - Not present in all binaries
    - Requires reading from the binary
- Usable through SymtabAPI

Static Analysis



- Use static analysis to determine Δ, the distance to the top of the stack frame, for each instruction

Undefined Stacks

- May see unknown changes to the stack pointer.

```
Δ=4    lea 4(%esp),%ecx
Δ=???  and $0xfffffff0,%esp
Δ=???  pushl 0xfffffffc(%ecx)
Δ=???  push %ecx
Δ=???  sub $20,%esp
       ...
```

- May have conflicting stack values

```
Δ=28  xorl %eax, %eax
Δ=24  pop %eax
Δ=24  jmp  ...
```

```
Δ=28  push $4
Δ=32  push $8
Δ=36  call foo
```

```
Δ=???  pop %edx
Δ=???  pop %eax
Δ=???  add $20, %esp
Δ=???  ret
```

Other Issues

- Some functions may "clean" their parent's stack:

func1:
```
push %eax
push %ebx
call func2
ret
```

func2:
```
push %ebp
mov %esp,%ebp
...
leave
ret 8
```

- Non-returning function calls interfere with analysis:

func1:
```
...
push %eax
push %ecx
call abort
```

func2:
```
push %ebp
mov %esp, %ebp
```

Static Analysis Results

Compiler	Functions	Functions with Frame Pointers	Functions w/ Undefined Stacks
gcc 4.1.2	234,955	233,787 (99.5%)	644 (0.2%)
icc v10.0	45,173	18,921 (41.9%)	3,019 (6.7%)

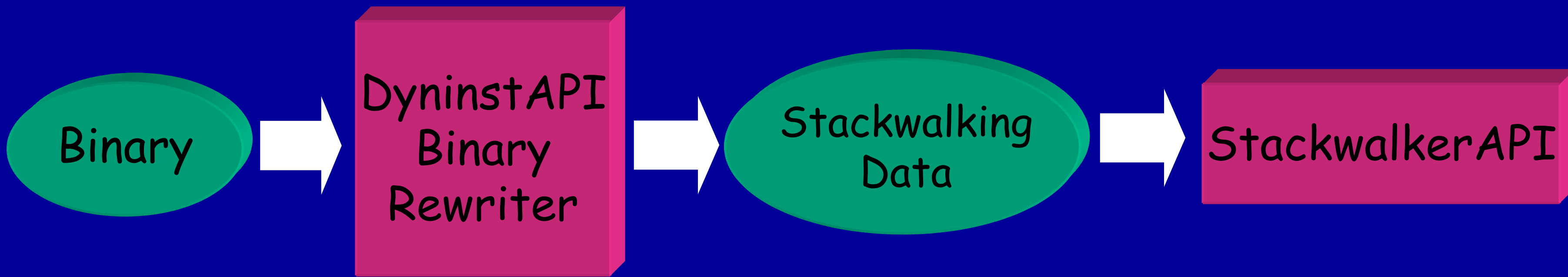
Static Analysis Results

- Manually found all non-returning functions in icc compiled gdb.

Recognize Non-Returning	Functions	Functions with Frame Pointers	Functions w/ Undefined Stacks
No	6,067	489 (8.06%)	1,007 (16.6%)
Yes	6,051	649 (10.37%)	10 (0.16%)

Implementation

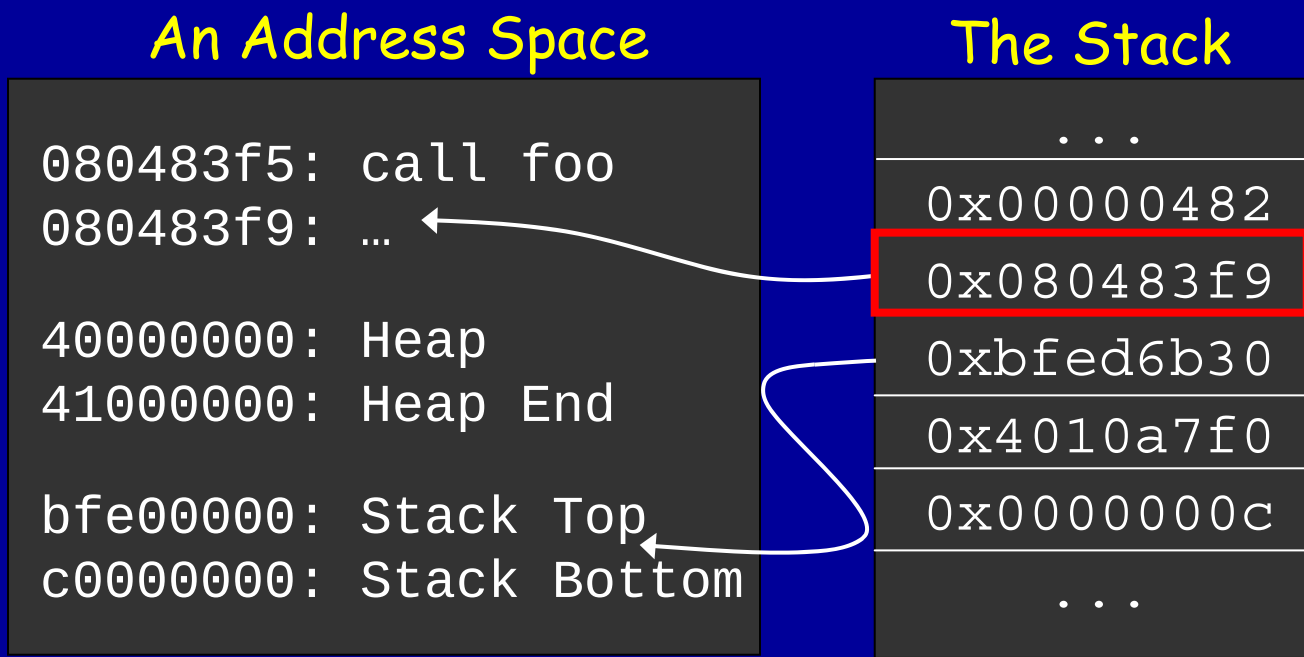
- Now
  - DyninstAPI runs analysis, produces result file
  - Result file is fed into StackwalkerAPI



- Goal
  - StackwalkerAPI runs analysis when needed

Heuristic Stack Searching

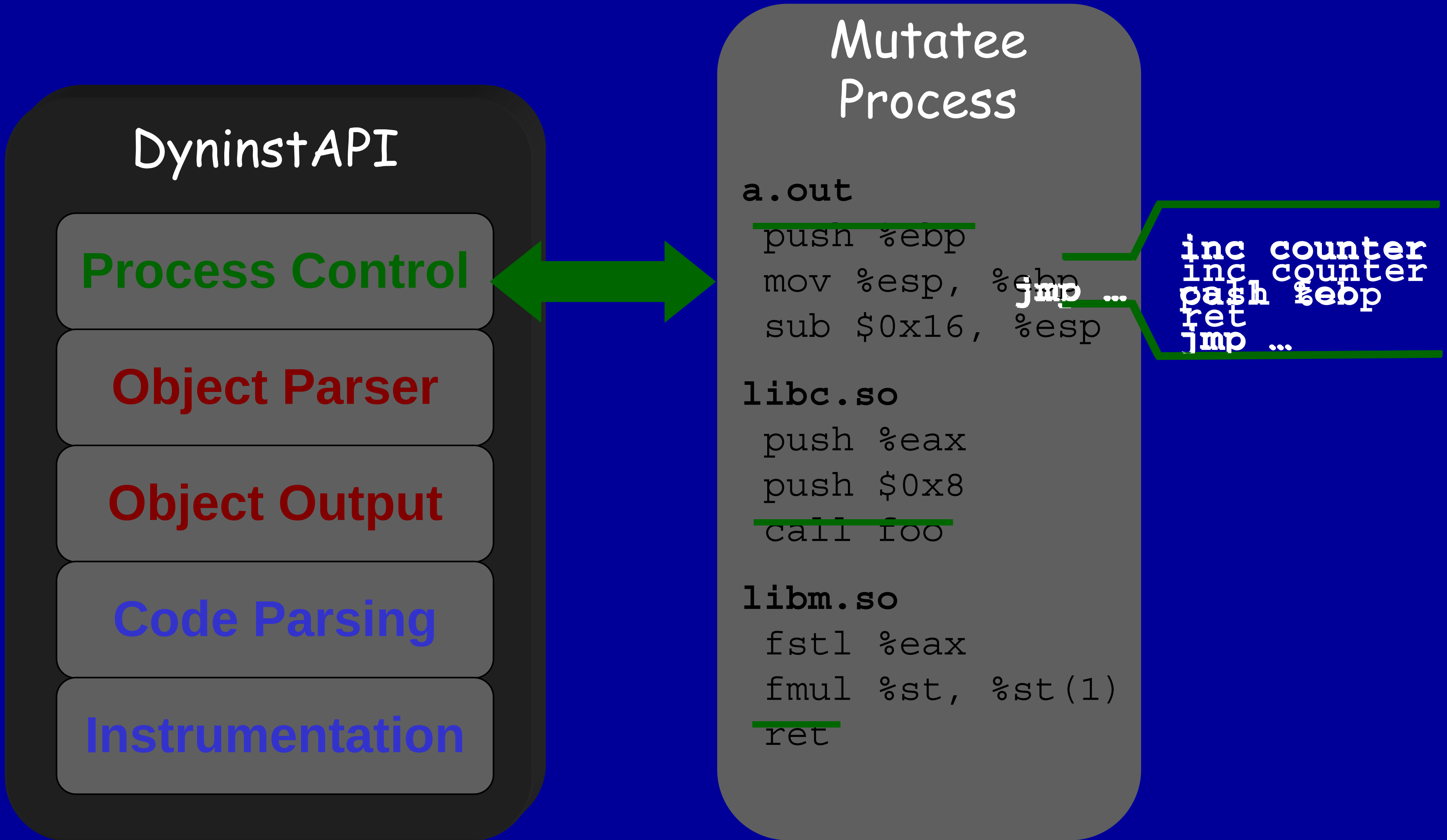
- Use heuristics to search the stack for frames



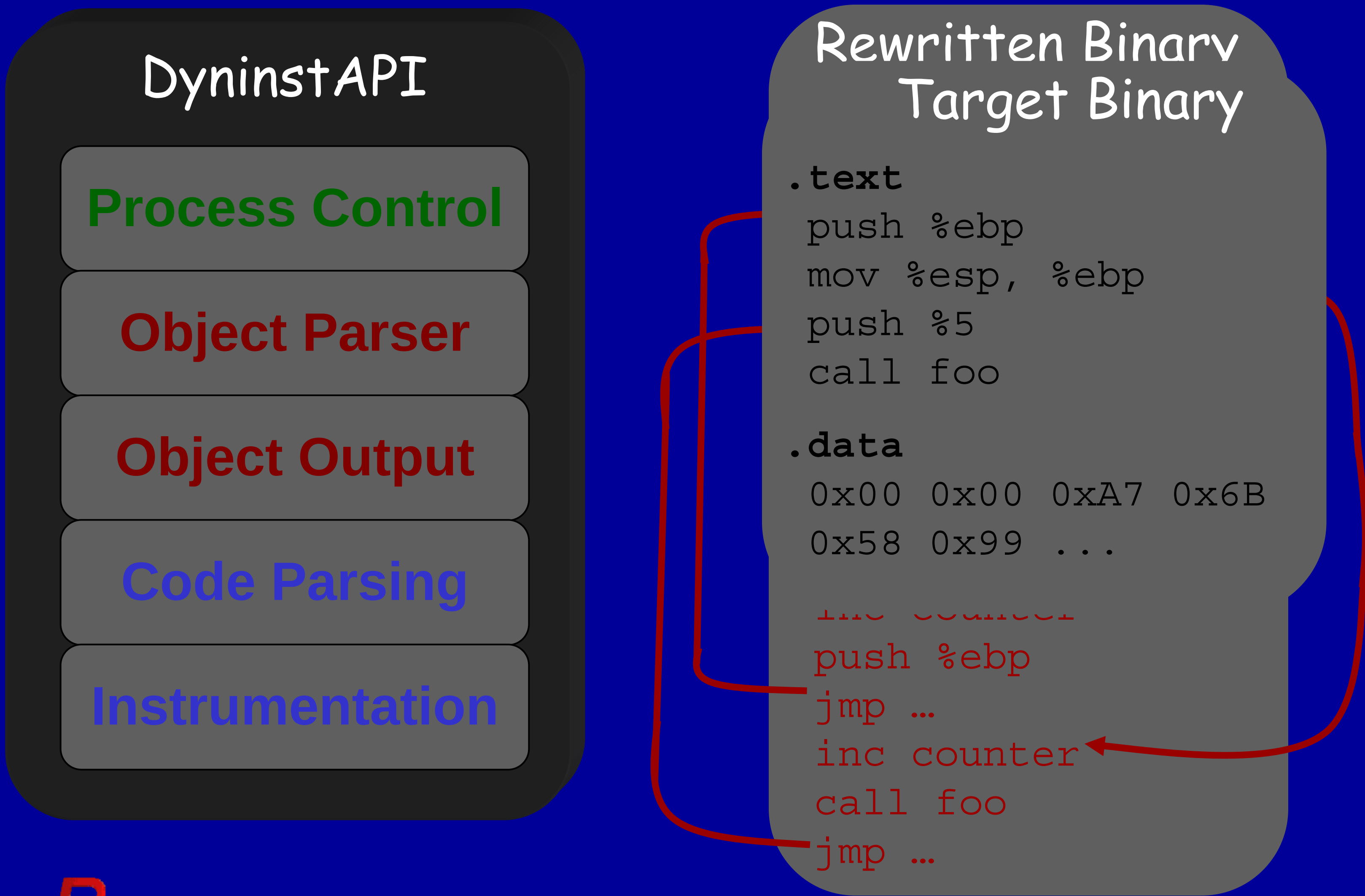
- An address is likely the top of a frame if …
  - ✓… it points to an instruction that follows a call
  - ✓… the following address points into the stack

Questions?

Dyninst and Static Rewriting



Dyninst and Static Rewriting



A Static Binary Rewriter

- Uses the same abstractions and interfaces as Dyninst
- Instrument and modify objects on disk
  - Instrument once, run many times
  - Run instrumented binaries on otherwise unsupported systems (e.g. BlueGene)
- Operates on unmodified binaries
  - No debug information required
  - No linker relocations required
  - No symbols required

Static Vs. Dynamic Rewriting

Static Rewriting	Dynamic Rewriting
✓Amortize parsing and instrumentation time	✓Insert and remove instrumentation at run time
✓Easier to port (no process control)	✓Execute instrumentation at a particular time (oneTimeCode)
✓Generate more efficient modified binaries	✓Tool can respond to run time events (shared library loads, exec, …)

The Binary Rewriter Interface

BPatch_addressSpace
- Instrumentation
- Image functions

Common Functionality

Dynamic Rewriting

Static Rewriting

BPatch_binaryEdit
- Open files
- Write files

BPatch_addressSpace

- Use **BPatch_addressSpace** for static and dynamic code instrumentation.

```
if (use_bin_edit)
  addr_space = bpatch.openFile(...)
else
  addr_space = bpatch.attachProcess(...)

...

addr_space->getImage()->findFunction(...);
addr_space->insertSnippet(...);
addr_space->replaceFunction(...);
```

BPatch_binaryEdit

- Open a file and its libraries for rewriting

a.out

libc.so | libstdc++.so | libpthread.so

libm.so

- Open a single file for rewriting

libbar.so

- Add new libraries to an application

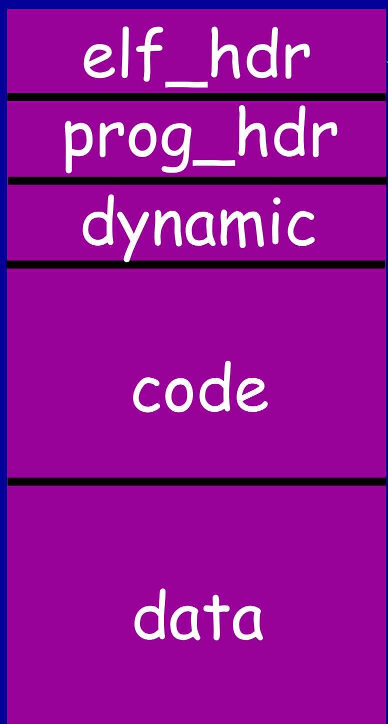
a.out | libinstr_helper.so

New Dyninst Requirements

- Need to write object files
  - Add new code
    - e.g., Add generated instrumentation code
  - Write changes to existing code.
    - e.g., Write trampoline jumps
  - Reference symbols in other libraries
    - e.g., Generate instrumentation that calls libc's write from the a.out
  - Update headers

- Start with Dyninst's existing instrumentation and parsing mechanisms.

Modifying the Binary

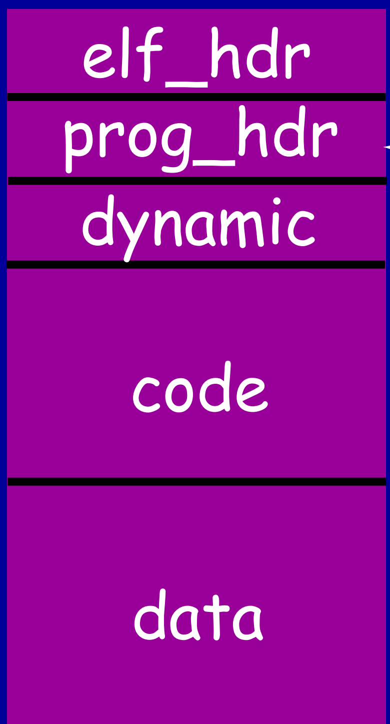


Elf Header contains:

•Meta-information about the object

•Pointers to the locations of important sections

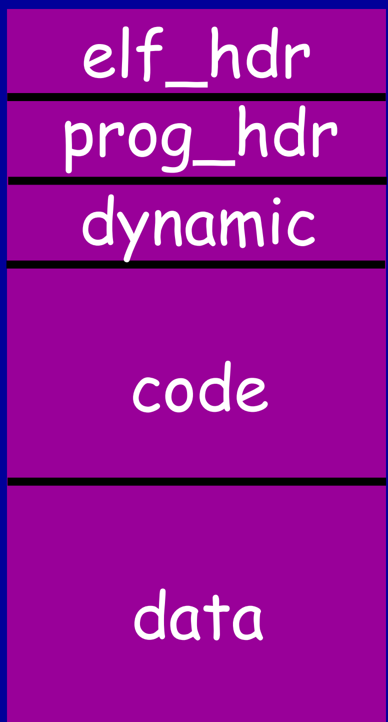
Modifying the Binary



Program Header contains:

- Information on how to lay out the binary in memory
- The related section header contains information on how the binary is laid out on disk.

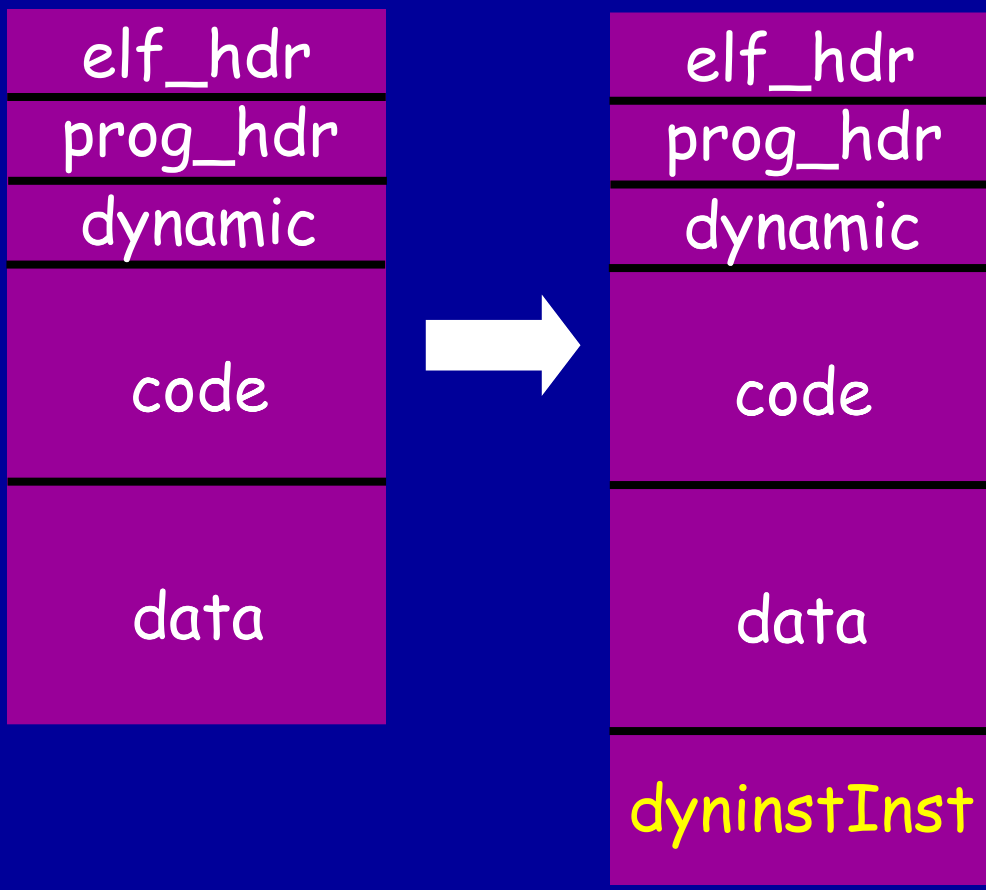
Modifying the Binary



Dynamic Section contains:

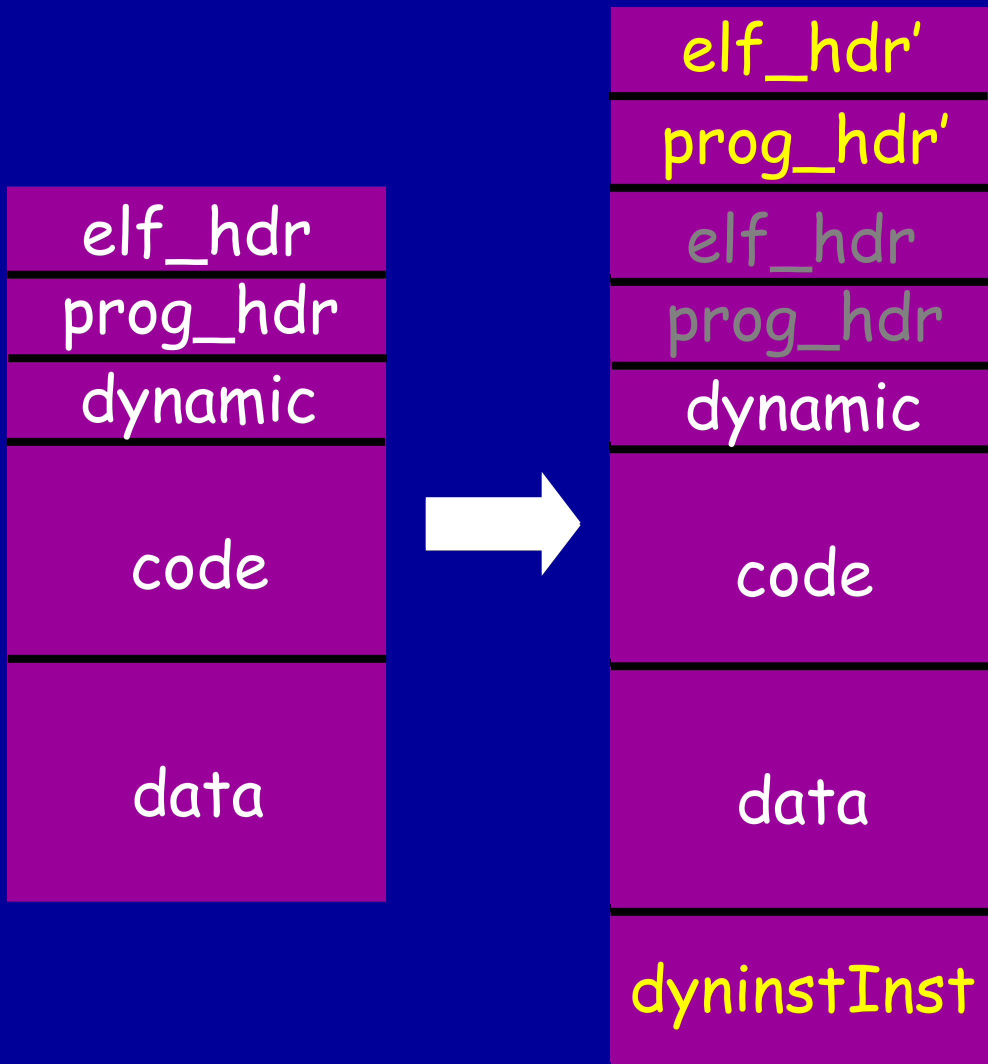
- How to resolve references to other libraries.
- Multiple sections involved:
    - Dynamic Symbol Table
    - Dynamic Strings Table
    - Relocation tables
    - Symbol Versioning info

Modifying the Binary



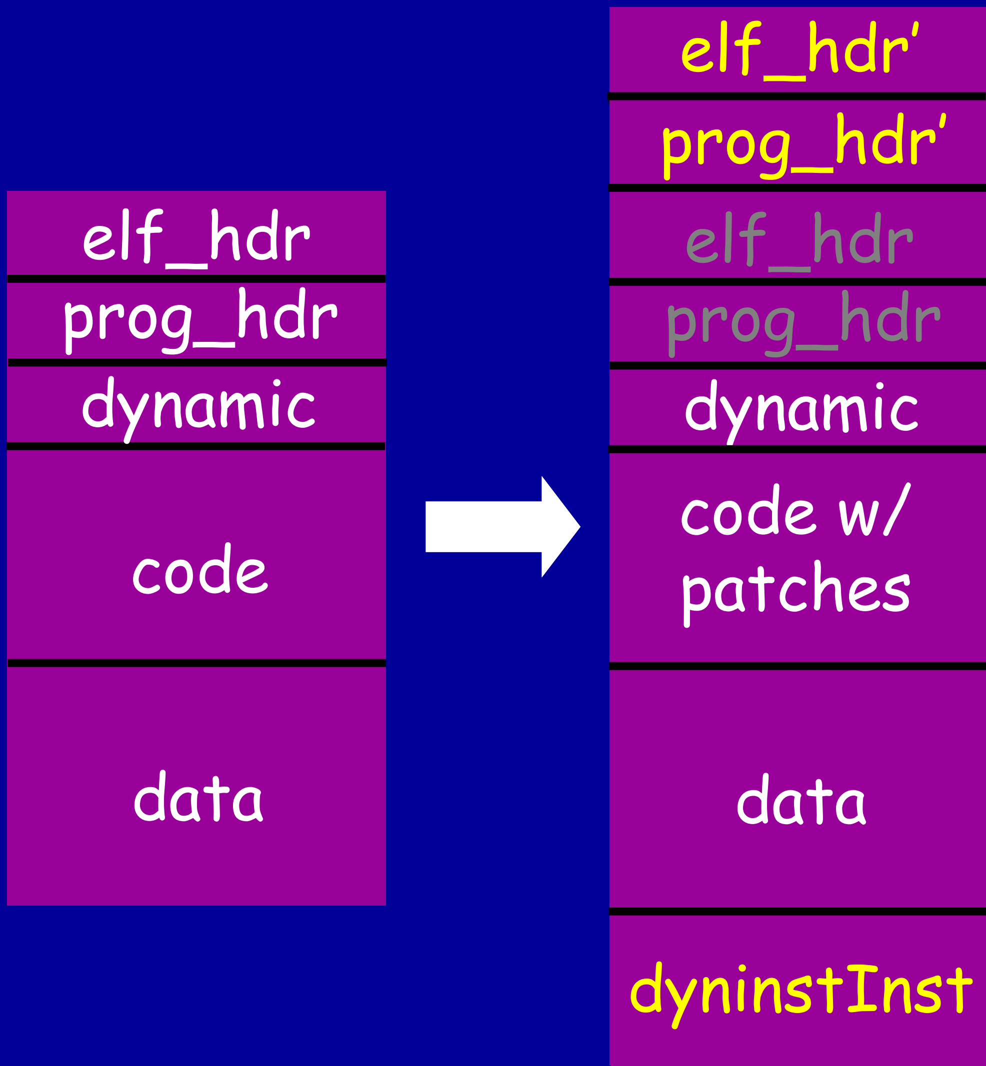
- Add space for instrumentation and relocated functions to end of object.

Modifying the Binary



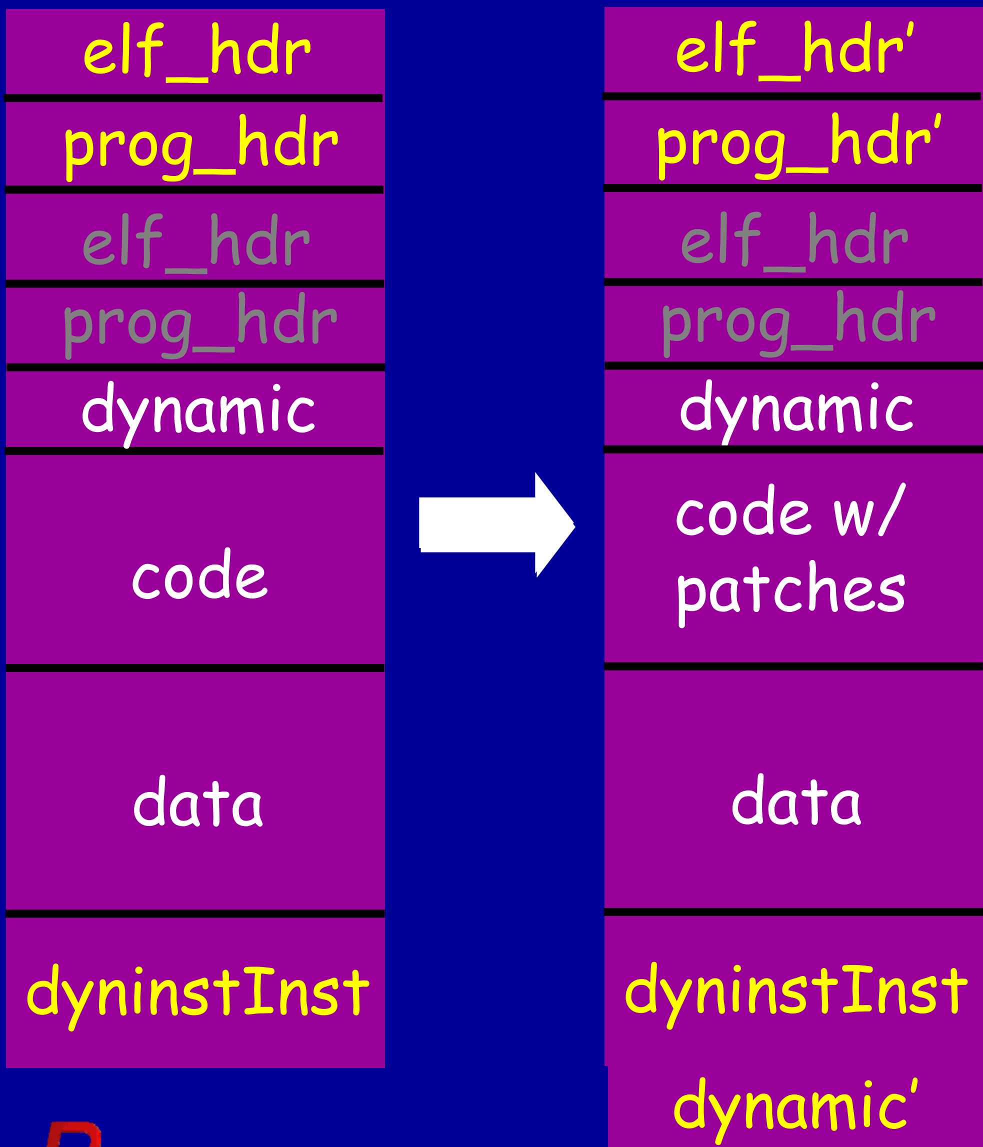
- Need to modify prog_hdr with new section info.
- Grow prog_hdr by copying it elsewhere.
- Linux bug means prog_hdr must follow elf_hdr

Modifying the Binary



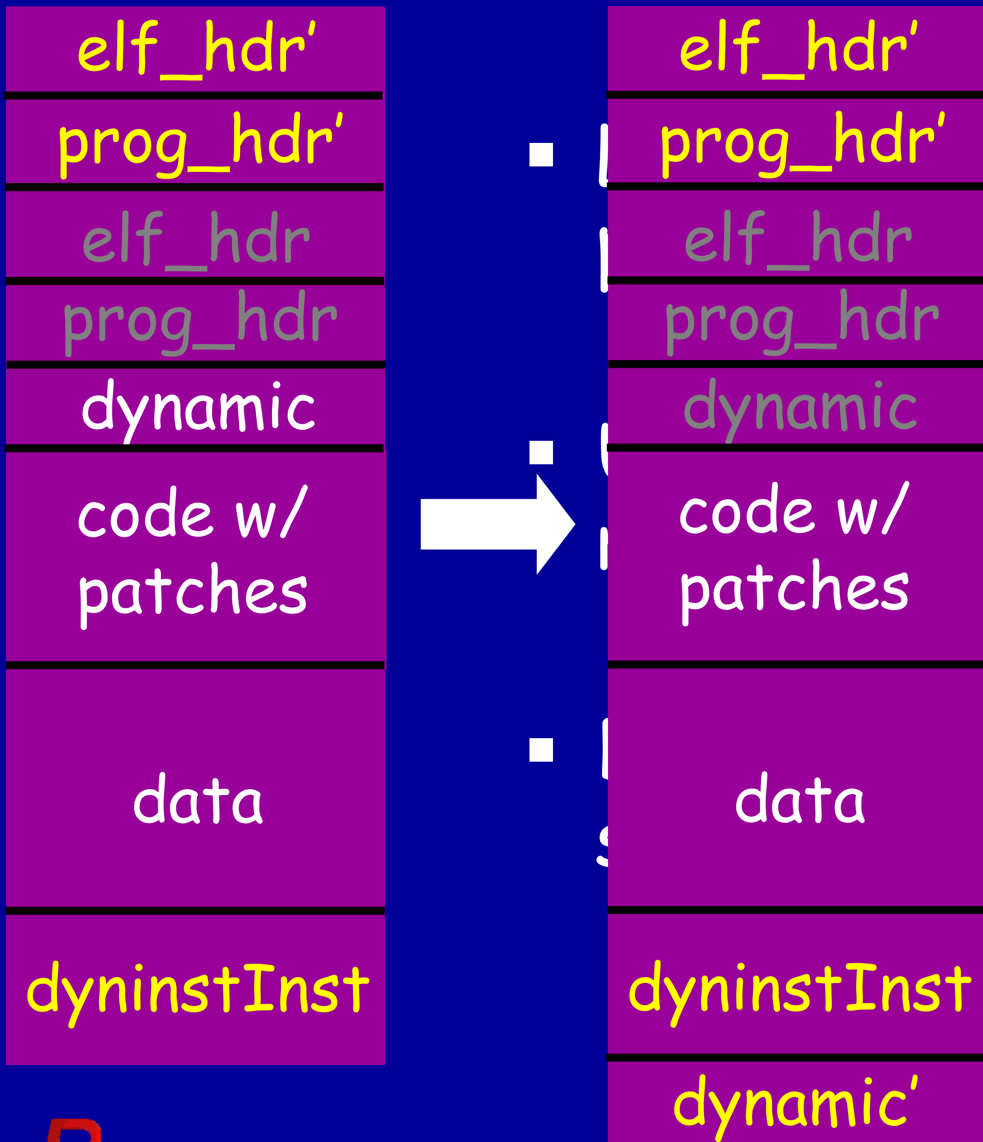
- Add trampolines and other Dyninst modifications by patching existing code.

Modifying the Binary



- Need to add to dynamic for external references made by instrumentation.
- Cannot grow dynamic, so copy to end of object.

Modifying the Binary



- opies of sections in
- ointers in elf_hdr to ew section locations.
- ve code or data

Current Status

- Beta of binary rewriter in Dyninst 5.2.
  - Static binaries
  - Dynamic objects (but not inter-library calls)
  - System V ELF platforms (Linux,BG/L,Solaris,…)
    - x86, x86-64, PPC, IA-64, SPARC
- Coming Soon in Dyninst 6.0
  - Inter-library calls in dynamic objects
  - Adding new libraries to an object

Questions?

The Deconstruction of Dyninst: The InstructionAPI

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The InstructionAPI Goal

Support analysis algorithms

Provide a model that is:

- Simple
- Portable
- Abstract

Instructions Are Complicated

Abstract instruction model	Portable Filters information Matches expectations of analysis algorithms
Platform-specific decoder	Non-portable No abstraction Can build analysis if you know platform details
Register Transfer Lists	Portable Anti-abstraction Great for code generation Wordy & awkward for analysis

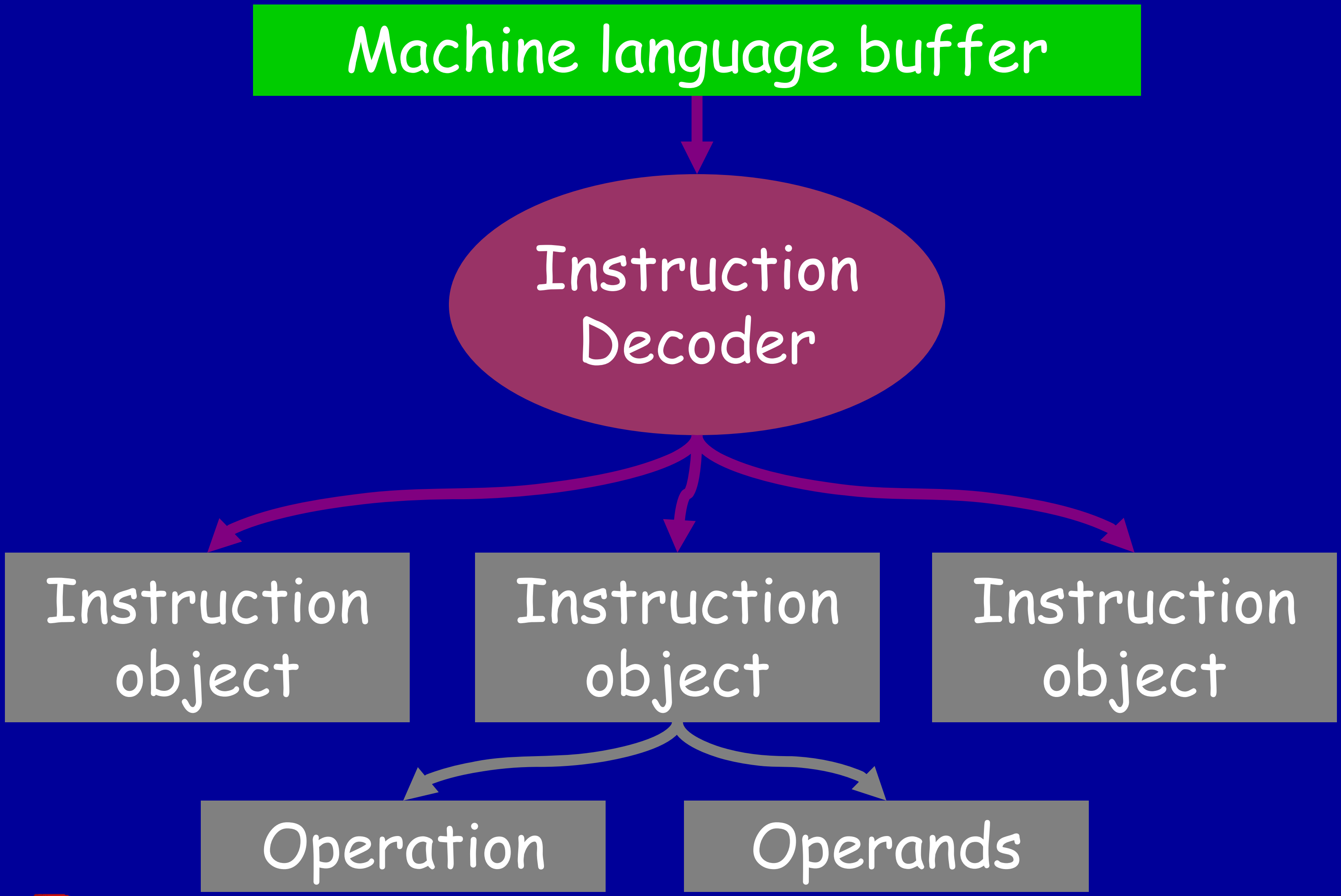
How Do We Build a Good Model?

- Make a good component
  - Abstract, platform-independent interfaces
    - Abstract away unnecessary platform/encoding specifics
    - Allow clean access to platform specifics
- Make it useful to customers
  - Concise model of syntax
  - Solid base for semantics
  - Direct queries for important analytic properties
- Focus on analysis
  - Good models exist for code generation
  - Code generation & analysis produce different abstractions

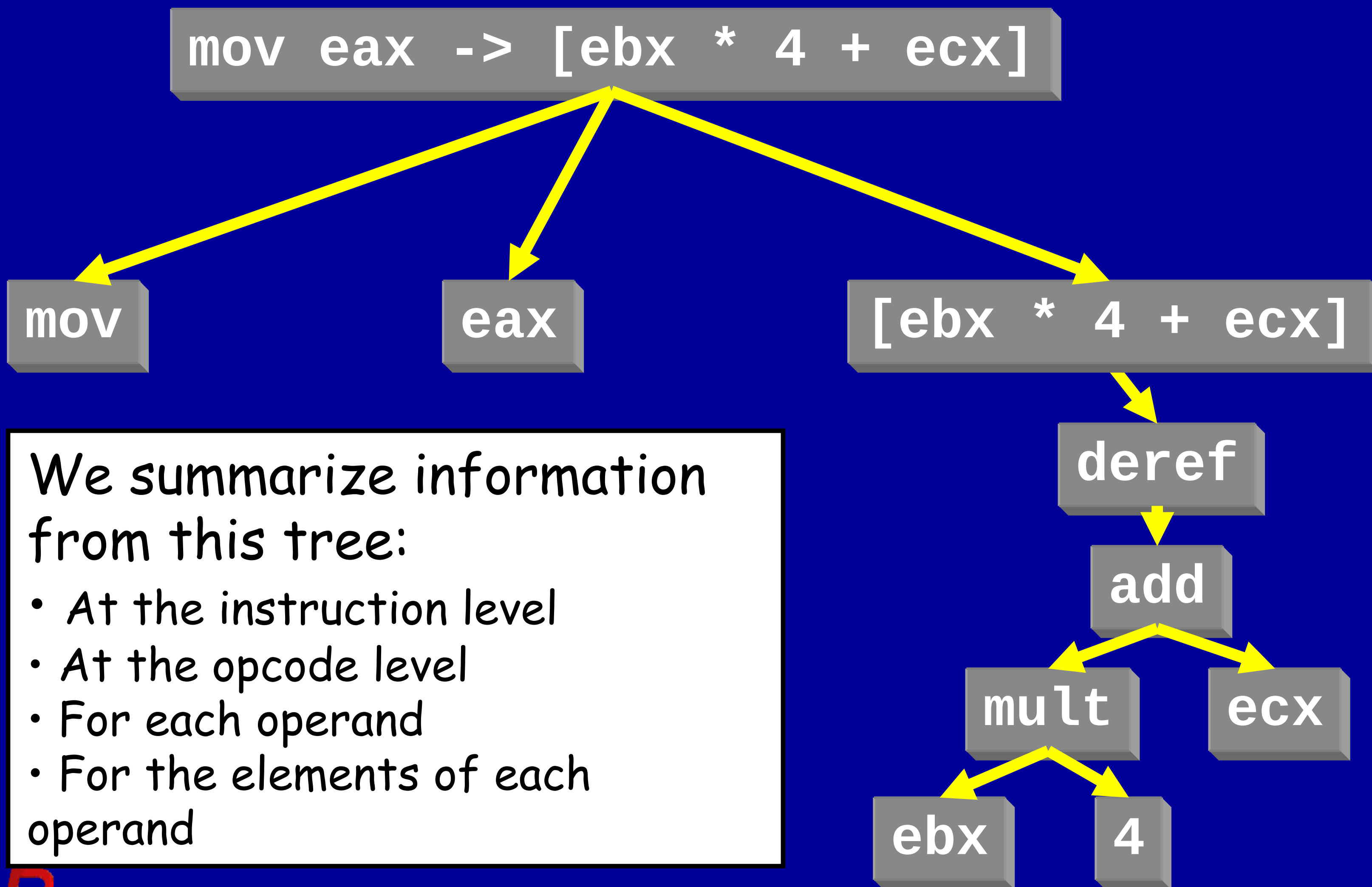
Comparison With Existing Tools

- VEX (Valgrind, RTL)
  - Doesn't provide interface for analysis queries
  - Represents semantics
- XED (PIN, Platform-specific)
  - Doesn't provide interface for analysis queries
  - Preserves all IA32 platform details
  - Closed-source license
- Both of these are focused on code generation, not analysis

The InstructionAPI System



Our Instruction Model



We summarize information from this tree:

- At the instruction level
- At the opcode level
- For each operand
- For the elements of each operand

Use Cases

- Register liveness
- Stack frame analysis
- Evaluation and update

Use Case: Register Liveness

- Building pre-liveness from post-liveness
  - Input: set of registers live post-instruction
  - Get registers read, written
  - $Live_{pre} = (Live_{post} \cup read(i)) - written(i)$

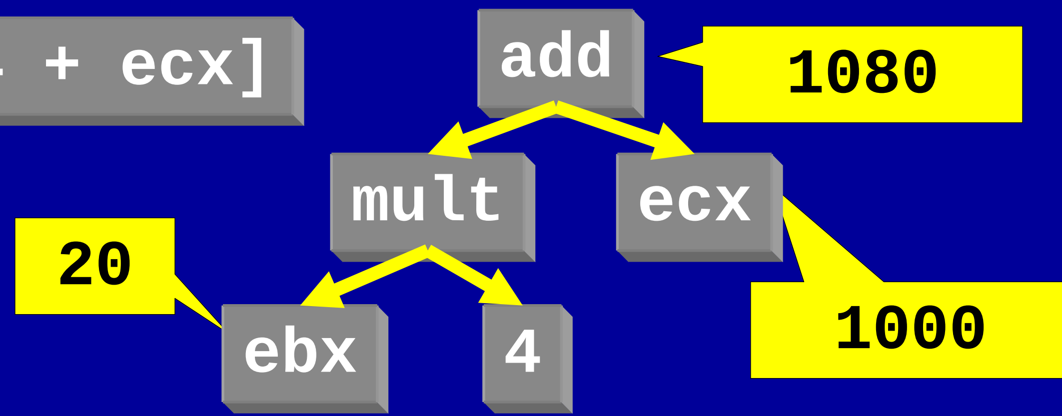
```
Instruction insn;
set<RegisterAST::Ptr> killedRegs;
set<RegisterAST::Ptr> liveRegs;

insn.getRegsRead(liveRegs);
insn.getRegsWritten(killedRegs);
set_difference(liveRegs, killedRegs);
```

Use Case: Stack Frame Analysis

- Find instructions that write the stack pointer: **`isUsed(r_ESP)`**
- If push/pop, get size of what's pushed: **`getOperand(i).size()`**
- If add/subtract, evaluate the operand that's not the stack pointer: **`getOperand(i).eval()`**
- If we have a known change, record it; if not, fall to **`UNKNOWN`**

Use Case: Evaluation & Update

```
mov eax -> [ebx * 4 + ecx]
```



Instruction defines memory at unknown address

Outside analysis gives us values for ebx, ecx

```
set<RegisterAST::Ptr> regsUsed;
set<Expression::Ptr> addressesDefinedExprs;
map<RegisterID, long> machineState;

insn.getRegsRead(regsUsed);
insn.getAddressesWritten(addressesDefinedExprs);
machineState[e_ebx] = 20;
machineState[e_ecx] = 1000;
UpdateRegisterValues(regsUsed, machineState);
addressUsed = addressesDefinedExprs.begin().eval();
```

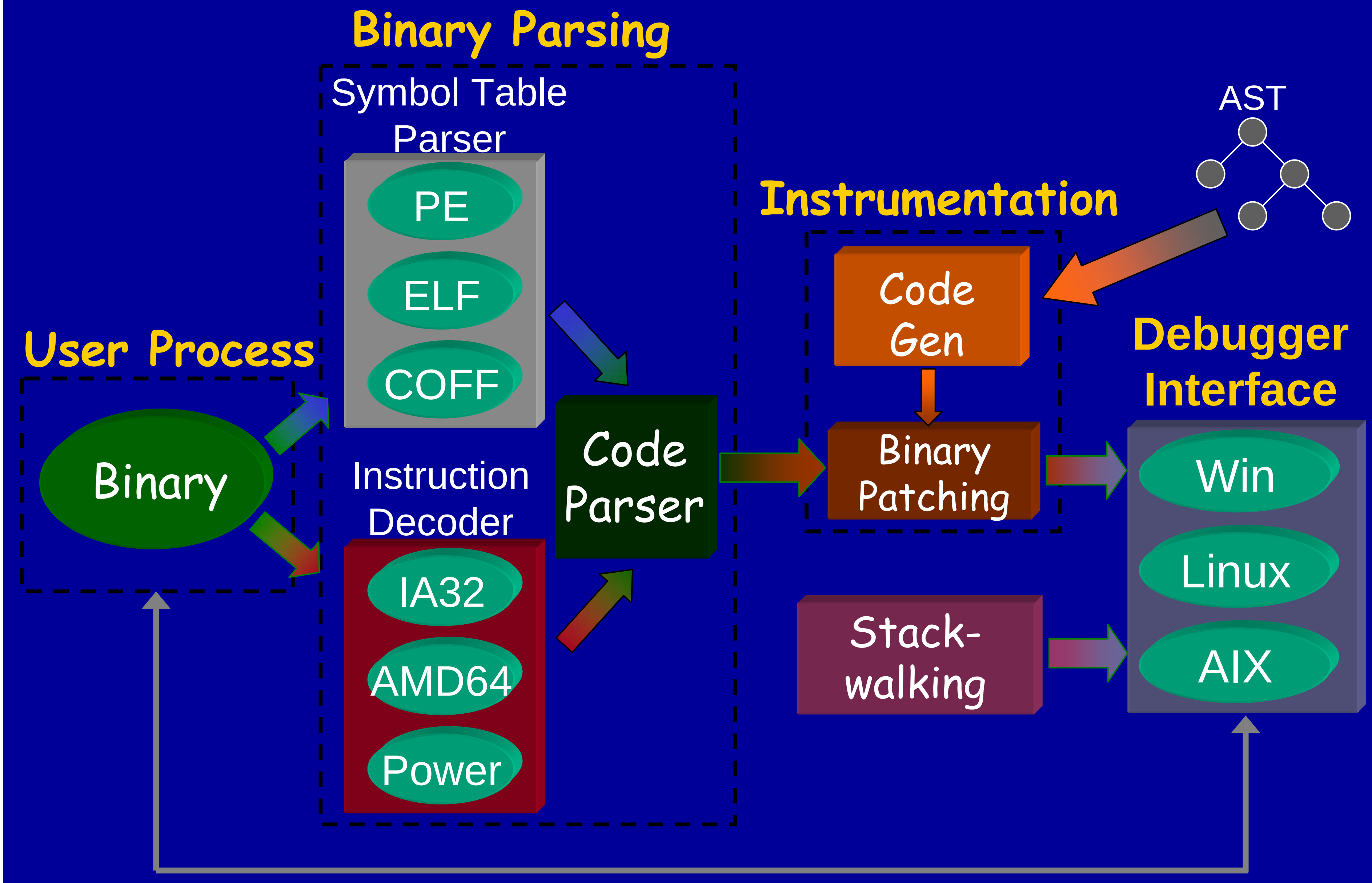
Current Status

- IA32/AMD64 completed
- Integration into Dyninst in progress
  - Stack analysis completed
  - Liveness completed
  - Parsing coming soon
- Manual available

Extensions and Future Work

- Provided by UW:
  - Additional platforms
    - IA64, Power, SPARC
  - Value-added libraries
    - Machine state abstraction
- Components we'd like:
  - Operation semantics
  - Code generation IR
  - Instruction parsers

Questions?


Binary Parsing
Symbol Table Parser
PE
ELF
COFF
Instruction Decoder
IA32
AMD64
Power
Code Parser
User Process
Binary
Instrumentation
Code Gen
Binary Patching
AST
Debugger Interface
Win
Linux
AIX
Stack-walking

SymtabAPI

- Generate new binary files
  - Add and modify sections
- Dynamic address mapping
  - Memory addresses to file offsets
- Parse debug information
  - Line information
  - Local variables and their types