Identifying Variables in x86 Executables

Gogul Balakrishnan
Thomas Reps

University of Wisconsin

Motivation

- Code-inspection tools for security analysts
  - dependence-based navigation ("code surfing")
- Analyses for identifying
  - security vulnerabilities and bugs
  - malicious code
  - commonalities and differences
- Platform for
  - code obfuscation and de-obfuscation
  - de-compilation
  - installation of protection mechanisms
  - remediation of security vulnerabilities

Why Executables?

- Reflects actual behaviors that may arise
- Allows platform-specific artifacts to be taken into account
  - memory layout
  - register usage
  - execution order
  - compiler bugs
  - Thompson-style attack
- Source code hides the low-level (actual) behaviors that implement high-level abstractions
- Source-code analyses typically make unsafe assumptions (e.g., that the program is ANSI-C compliant)
  - loss of fidelity can allow vulnerabilities to escape notice

Puzzle

```
int callee(int a, int b) {
  int local;
  if (local == 5) return 1;
  else return 2;
}
```

Standard prolog		Prolog for 1 local	
push	ebp	push	ebp
mov	ebp, esp	mov	ebp, esp
sub	esp, 4	push	ecx

Answer: 1

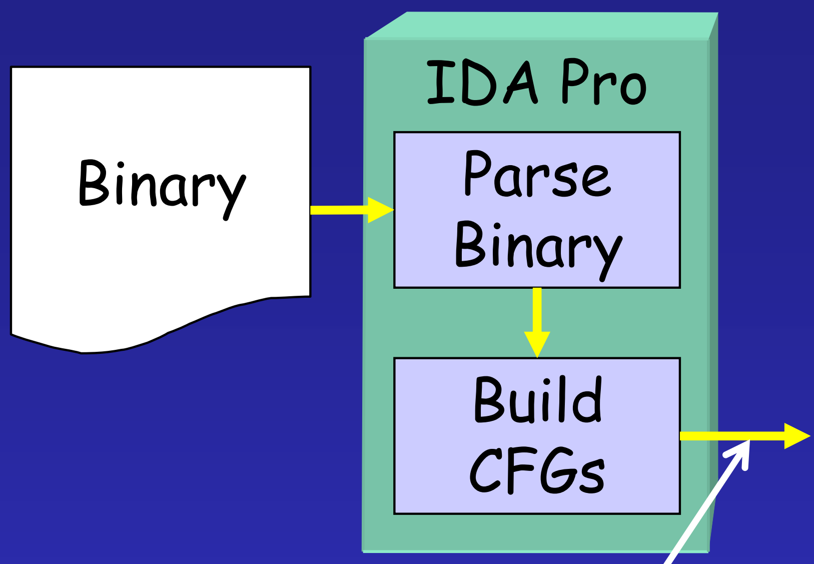
(for the Microsoft compiler)

```
int main() {
  int c = 5;
  int d = 7;

  int v = callee(c,d);
  // What is the value of v here?
  return 0;
}
```

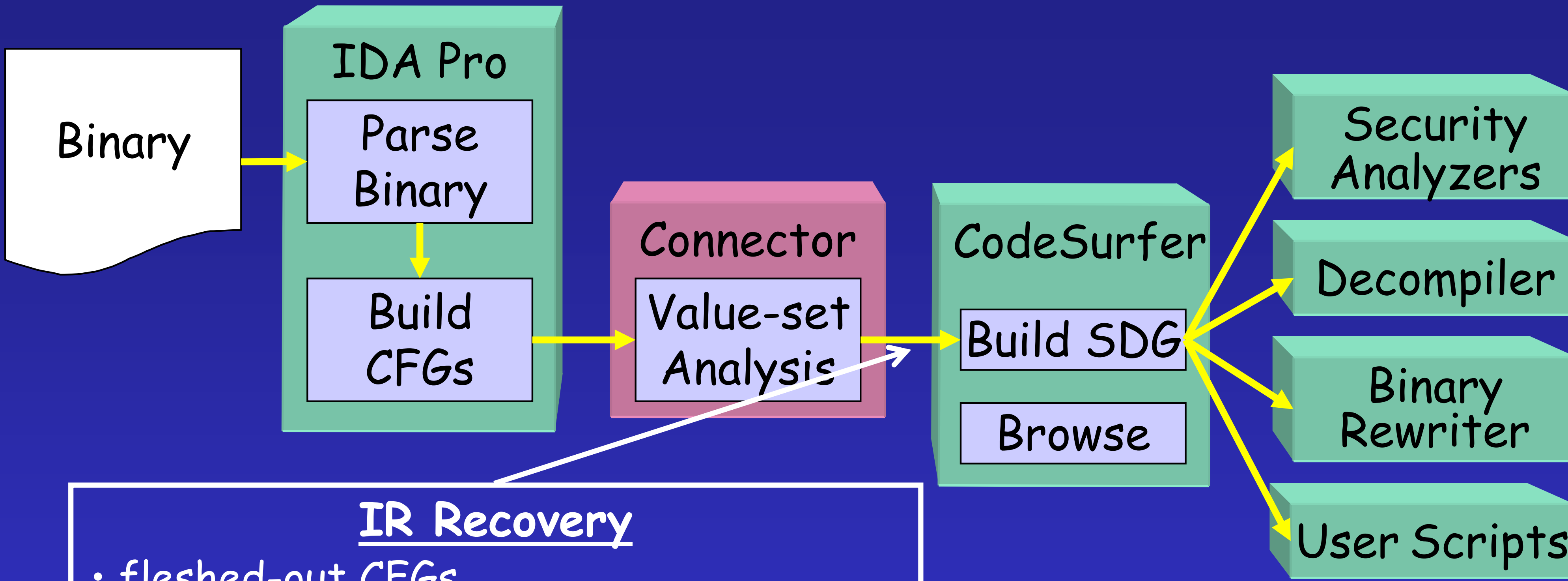
```
mov     [ebp+var_8], 5
mov     [ebp+var_C], 7
mov     eax, [ebp+var_C]
push    eax
mov     ecx, [ebp+var_8]
push    ecx
call    _callee
. . .
```

CodeSurfer/x86 Architecture



Initial estimate of
- code vs. data
- procedures
- call sites
- malloc sites

CodeSurfer/x86 Architecture



IR Recovery

- fleshed-out CFGs
- fleshed-out call graph
- used, killed, may-killed variables for CFG nodes
- points-to sets
- reports of violations
- [variables]
- [types: base types, pointer types, structs, and classes]

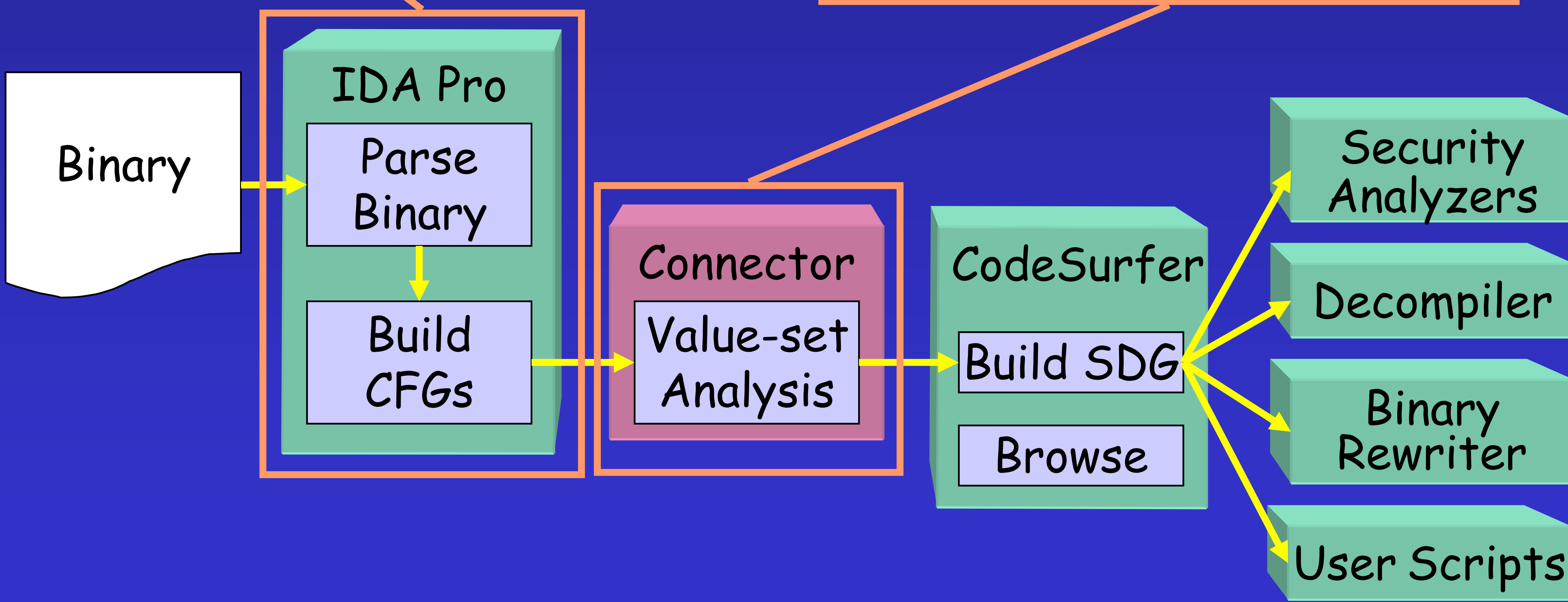
Scope

- Programs that conform to a "standard compilation model"
  - procedures
  - activation records
  - global data region
  - heap, etc.
- Report violations
  - violations of stack protocol
  - return address modified within procedure

Technical Challenges

- Distinguishing between code and data
- Identifying variables

- Identifying parameters
- Resolving indirect jumps
- Resolving indirect calls
- Identifying may-aliases



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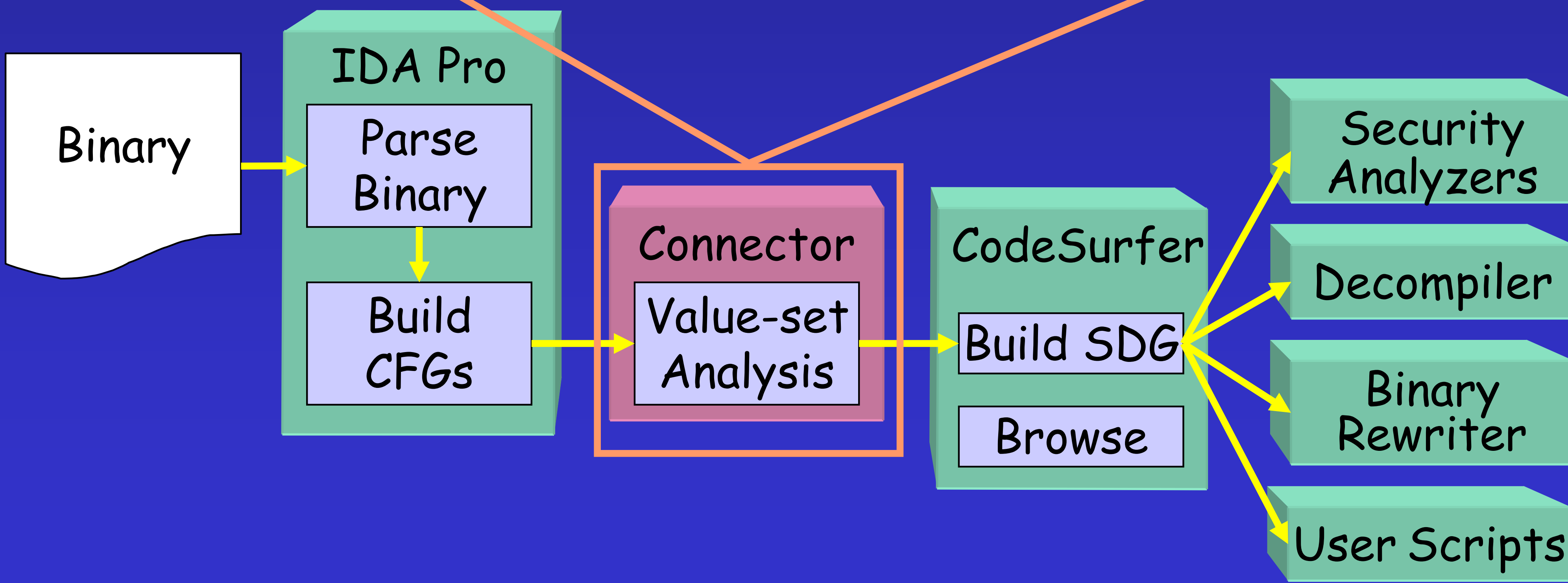

Running Example

```c
int arrVal=0, *pArray2;

int main() {
   int i, a[10], *p;
  /* Initialize pointers */
   pArray2 = &a[2];
   p = &a[0];
  /* Initialize Array */
   for(i = 0; i<10; ++i) {
      *p = arrVal;
      p++;
   }
  /* Return a[2] */
   return *pArray2;
}
```

```asm
; ebx ⇔ variable i
; ecx ⇔ variable p

sub     esp, 40         ;adjust stack
lea     edx, [esp+8]    ;
mov     [8], edx        ;pArray2=&a[2]
lea     ecx, [esp]      ;p=&a[0]
mov     edx, [4]        ;

loc_9:
   mov     [ecx], edx   ;*p=arrVal
   add     ecx, 4       ;p++
   inc     ebx          ;i++
   cmp     ebx, 10      ;i<10?
   jl      short loc_9  ;

mov     edi, [8]     ;
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add     esp, 40
retn
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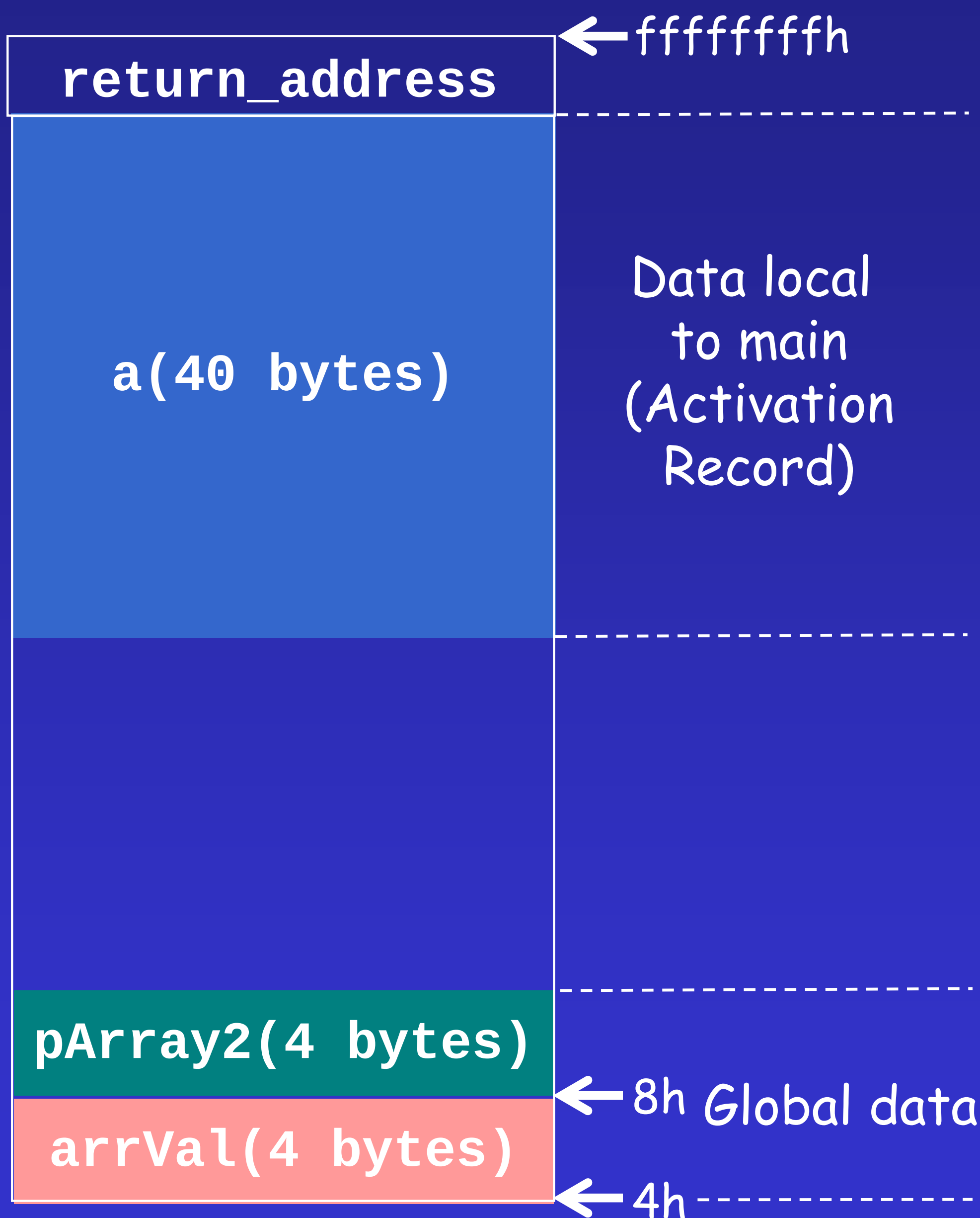


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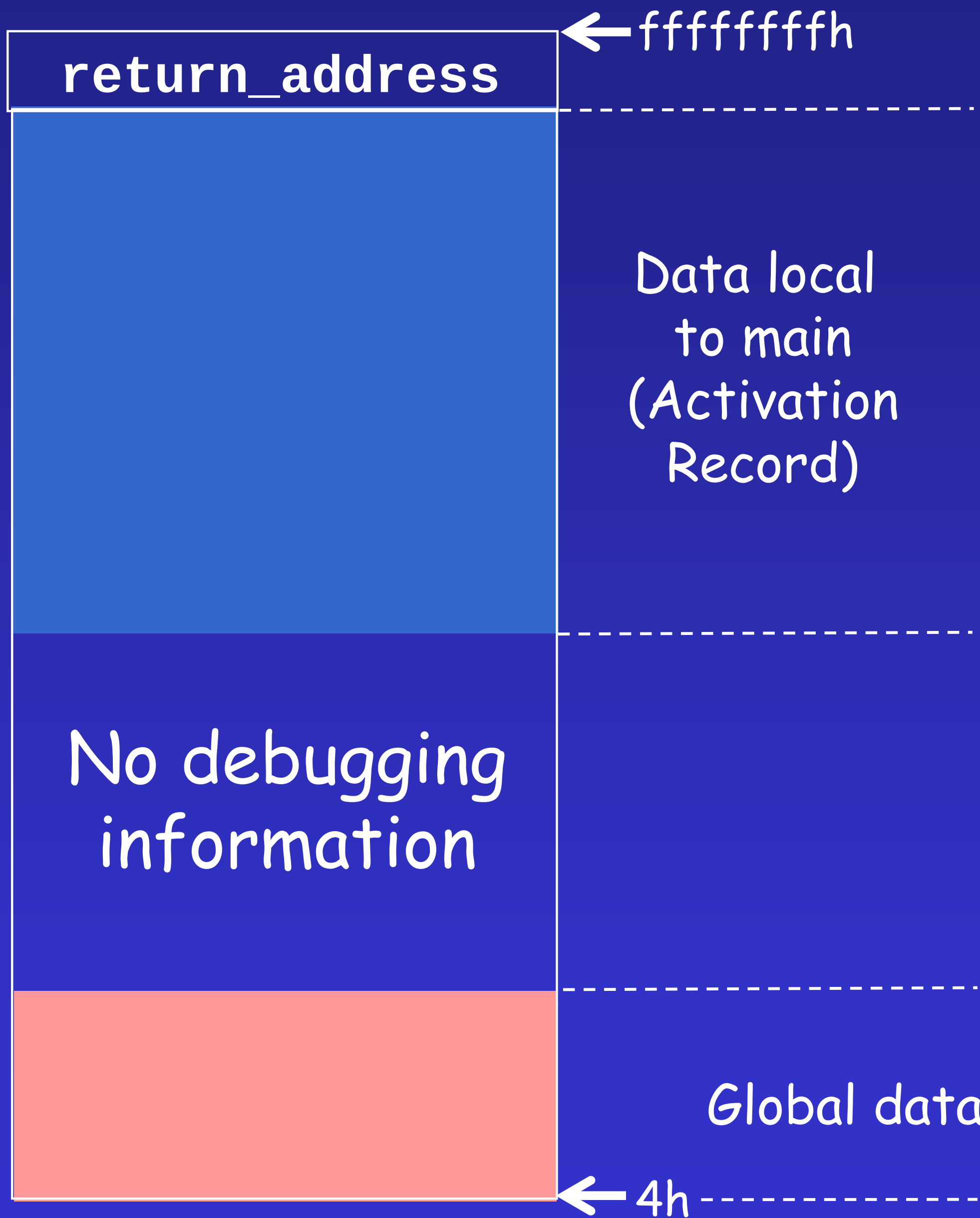


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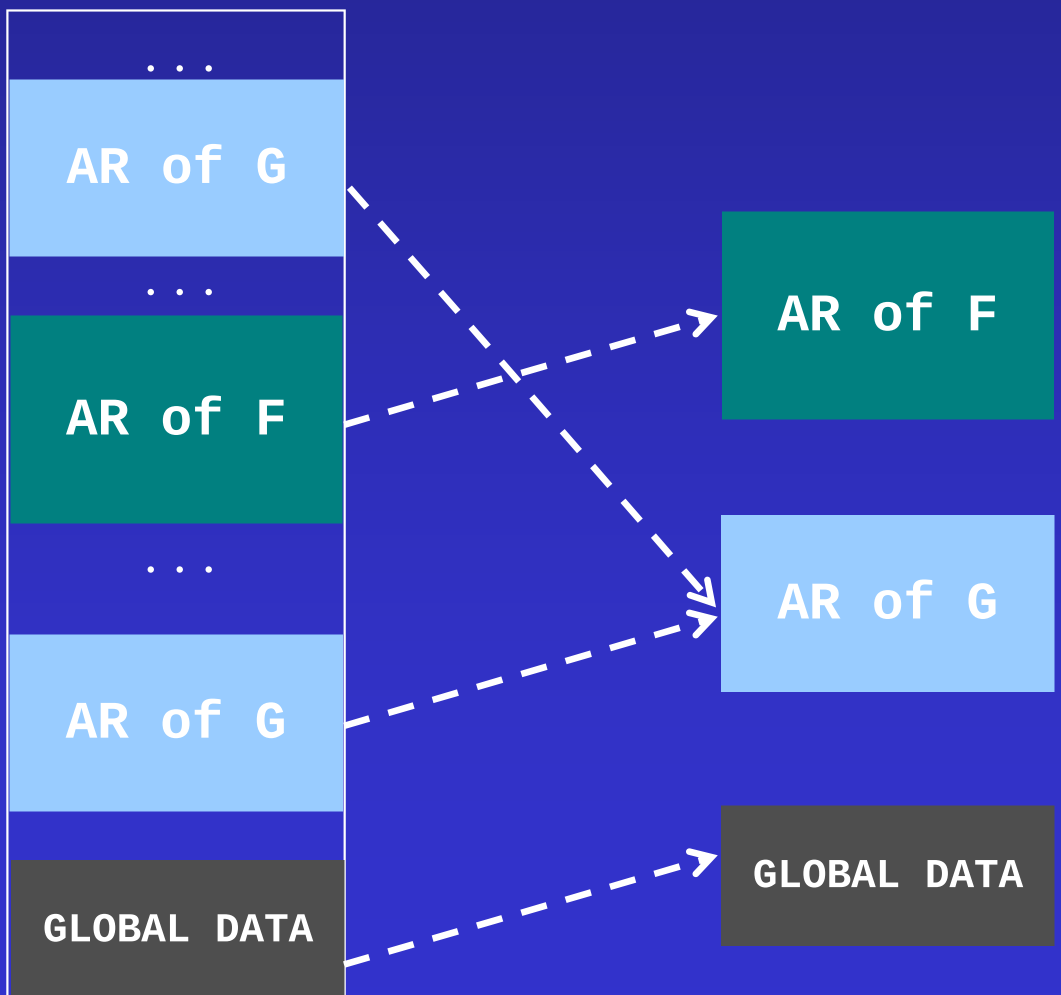
Identifying Variables

- An abstraction of concrete memory configurations
  - Memory regions

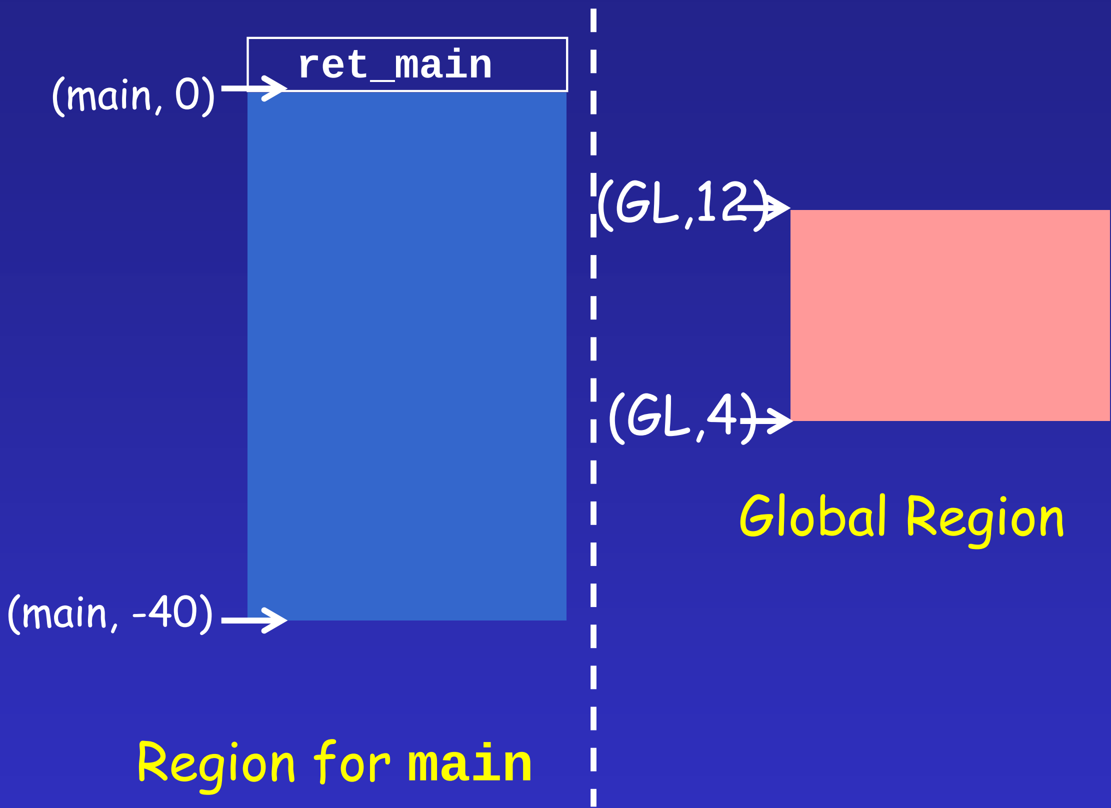
- Infer layout of memory regions
  - A-locs (like variables)

Memory Regions

- An abstraction of concrete memory configurations
  - Idea: group similar runtime addresses
  - e.g., collapse the runtime ARs for each procedure, malloc-sites, global data



Example - Memory Regions

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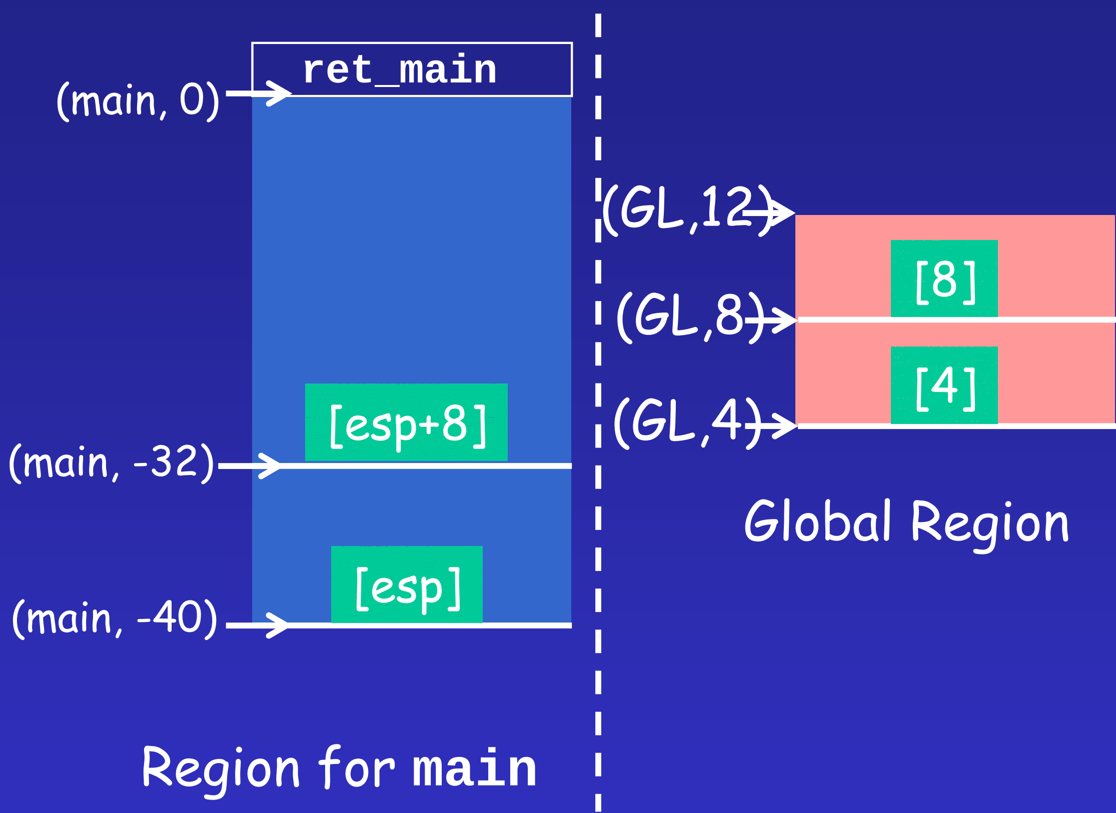
Infer Layout of Memory Regions

- Data-layout known at assembly/compile time
  - some variables held in registers
  - global variables → absolute addresses
  - local variables → offsets in stack frame
- A-locs
  - locations between consecutive addresses
  - locations between consecutive offsets
  - registers

Example - A-locs

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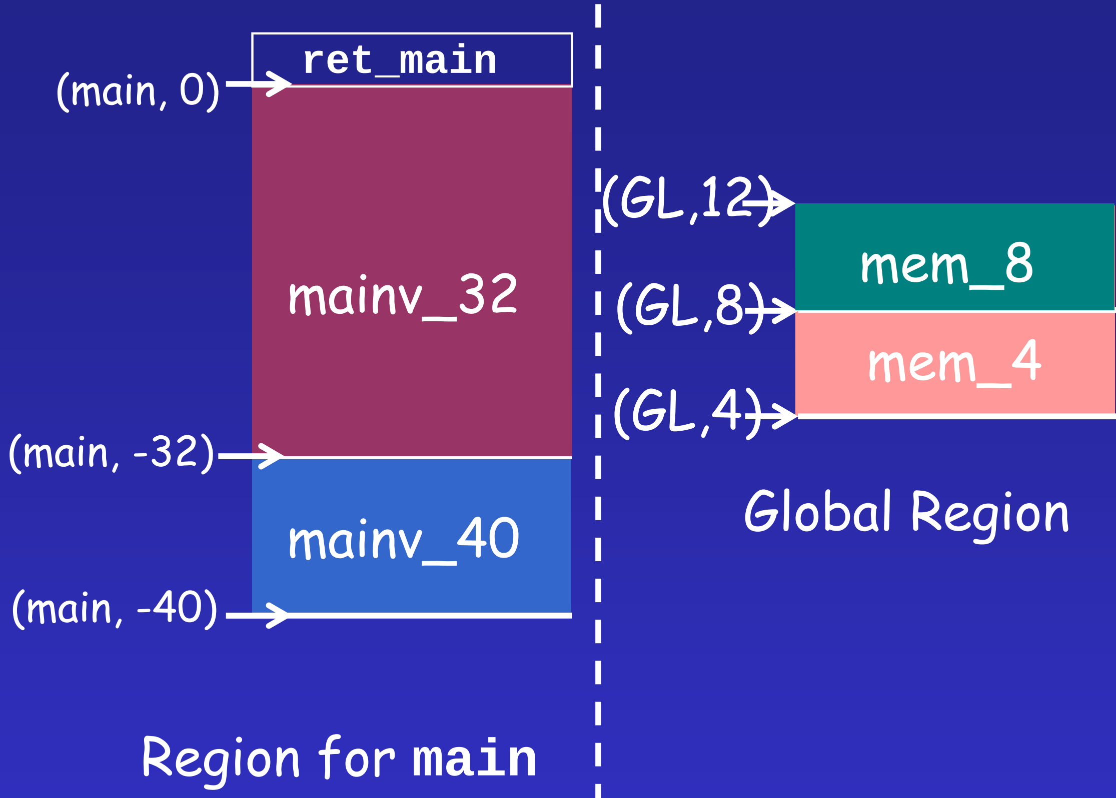


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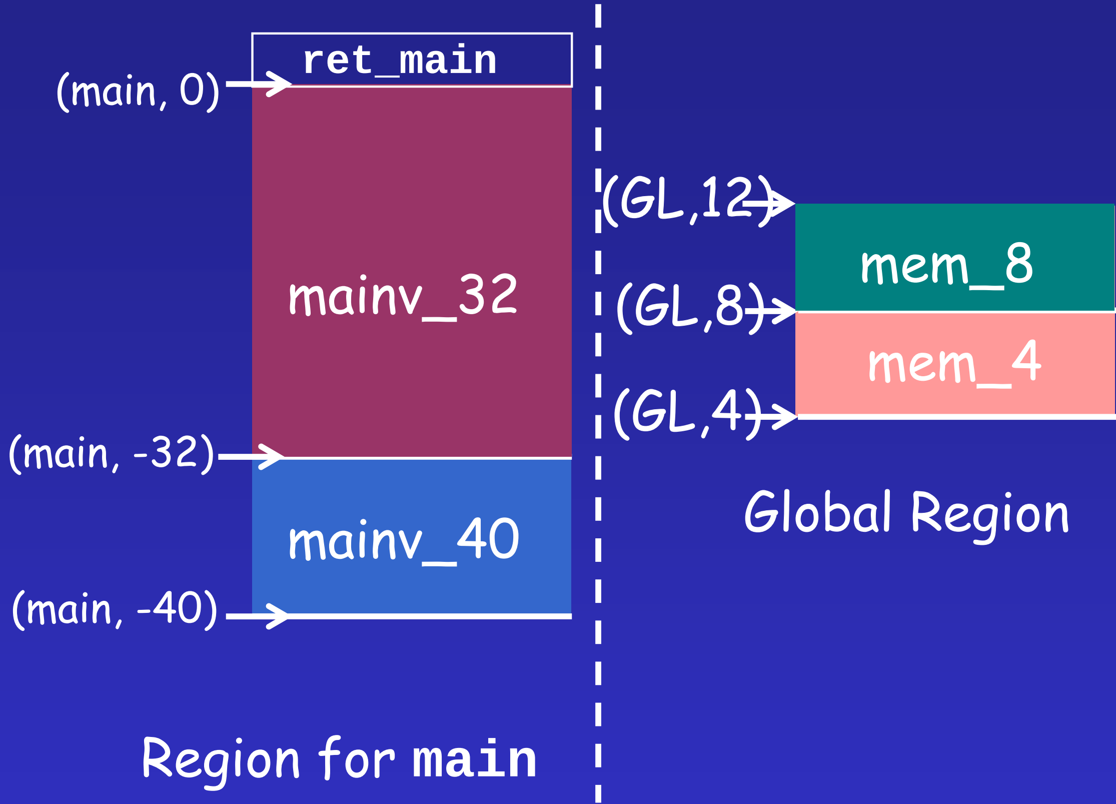



```
; ebx ⇔ variable i
; ecx ⇔ variable p

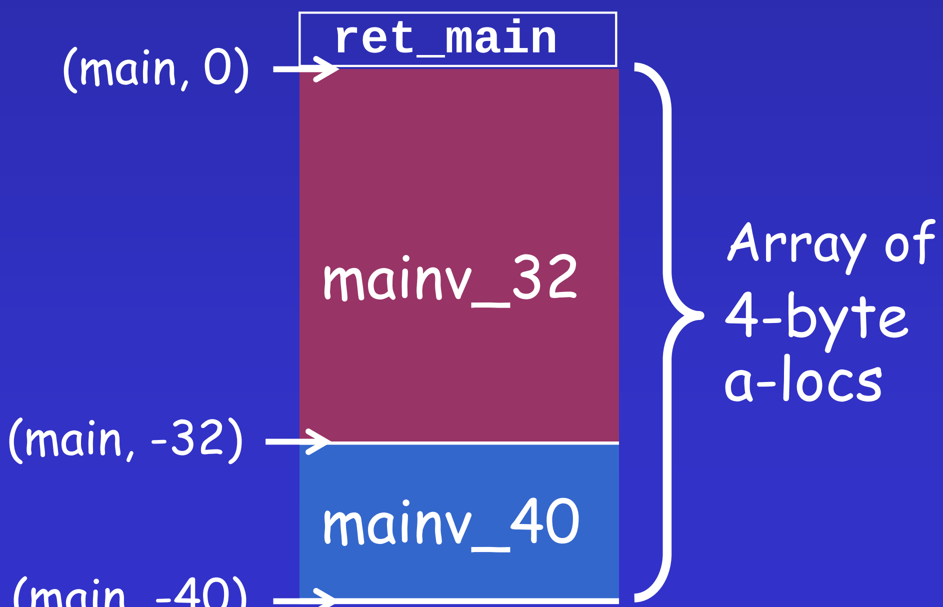
sub     esp, 40          ;adjust stack
lea     edx, &mainv_32;
mov     mem_8, edx       ;pArray2=&a[2]
lea     ecx, &mainv_40;p=&a[0]
mov     edx, mem_4       ;

loc_9:
    mov     [ecx], edx  ;*p=arrVal
    add     ecx, 4      ;p++
    inc     ebx         ;i++
    cmp     ebx, 10     ;i<10?
    jl      short loc_9 ;

mov     edi, mem_8       ;
mov     eax, [edi]   ;return *pArray2
add     esp, 40
retn
```

Better Identification of Variables

- IDAPro A-locs
  - Based on explicitly specified addresses/offsets
- VSA provides access patterns for indirect operands
  - **ecx** $\rightarrow$ ($\perp$, 4[0,9]-40)

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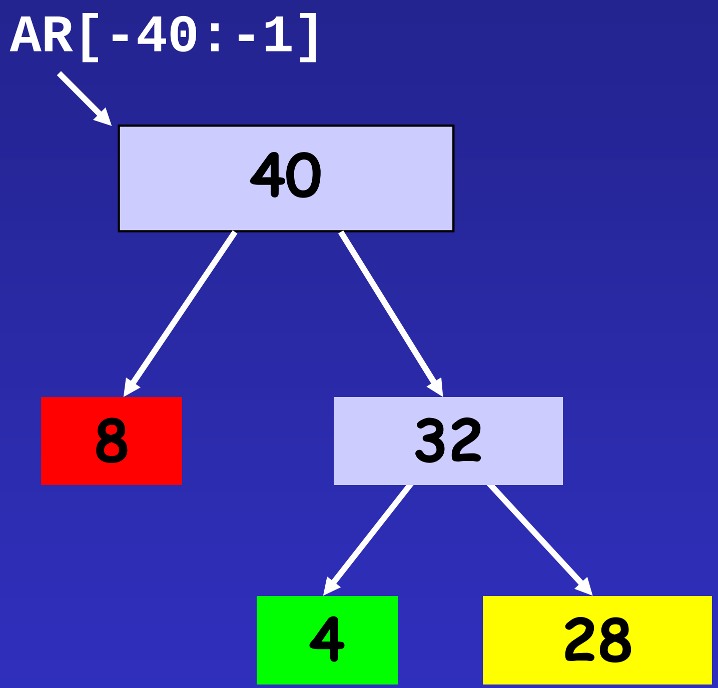
Aggregate Structure Identification

- Partition aggregates according to the program's memory-access patterns
  - original motivation: Y2K [Ramalingam et al. POPL 99]
- Uses in our context
  - improved identification of variables
    - identifies a better set of a-locs
      - ⇒ better IR ⇒ fewer false alarms
  - recovery of type information
    - identifies structs and arrays
    - propagates type information from known parameter types (system calls & library functions)
      - ⇒ better de-compilation

Aggregate Structure Identification

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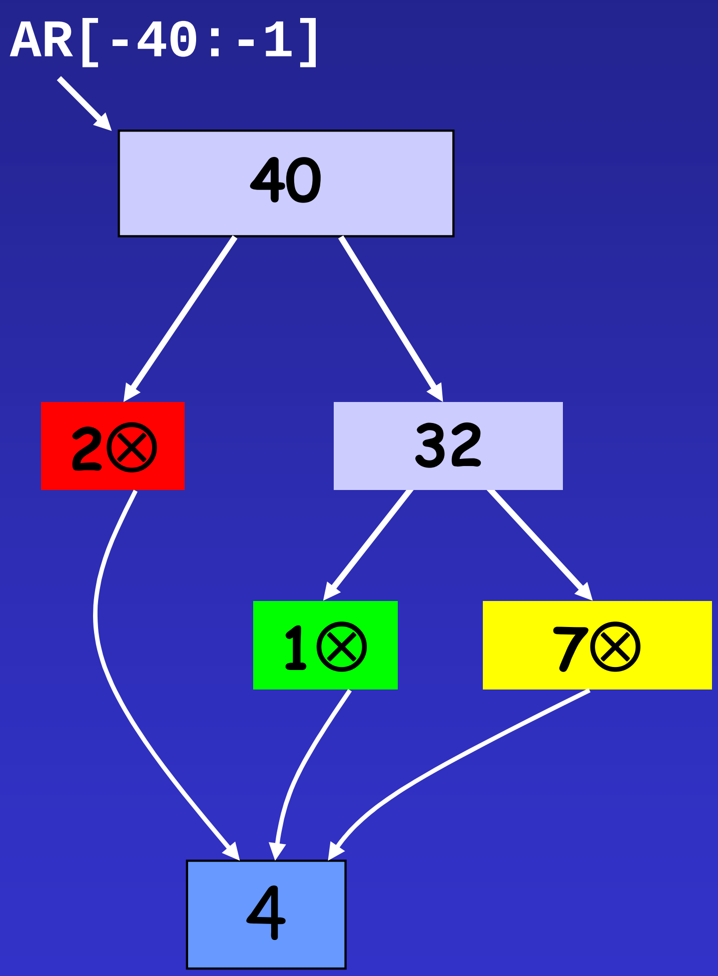


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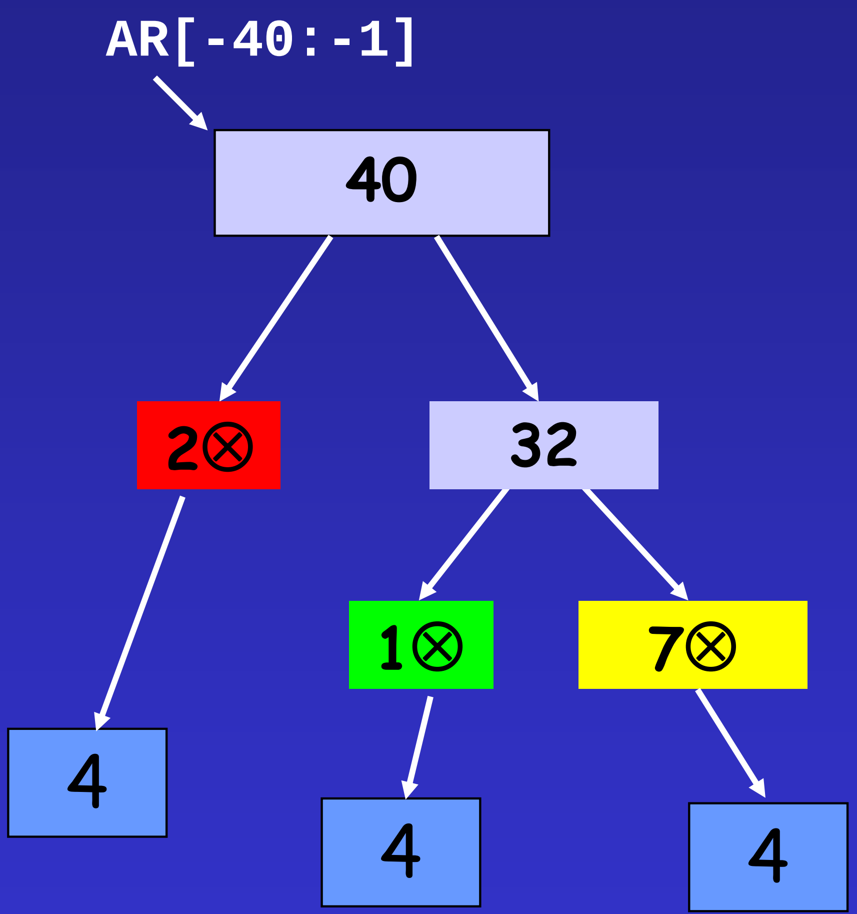


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ASI: two arrays; one scalar

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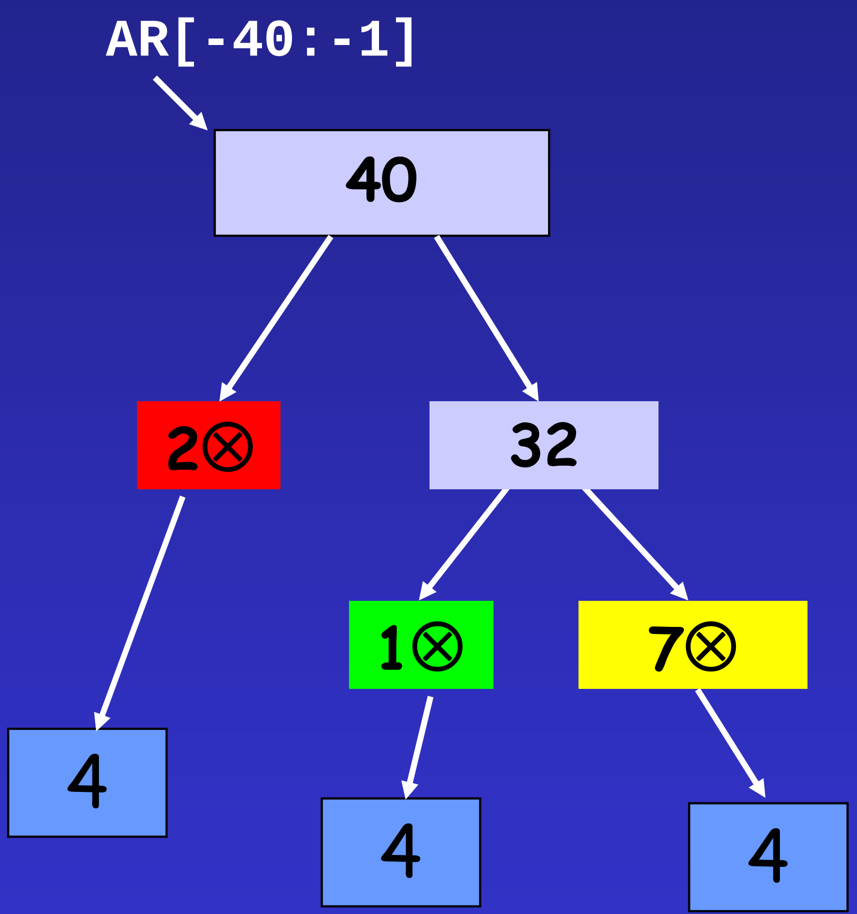
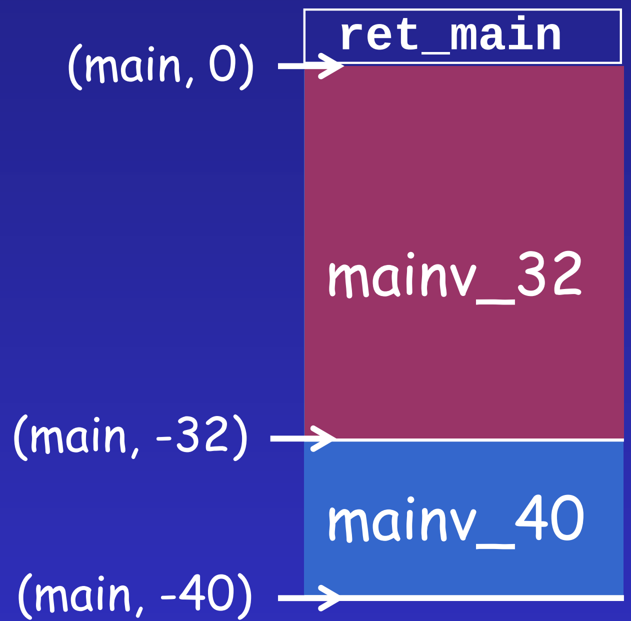


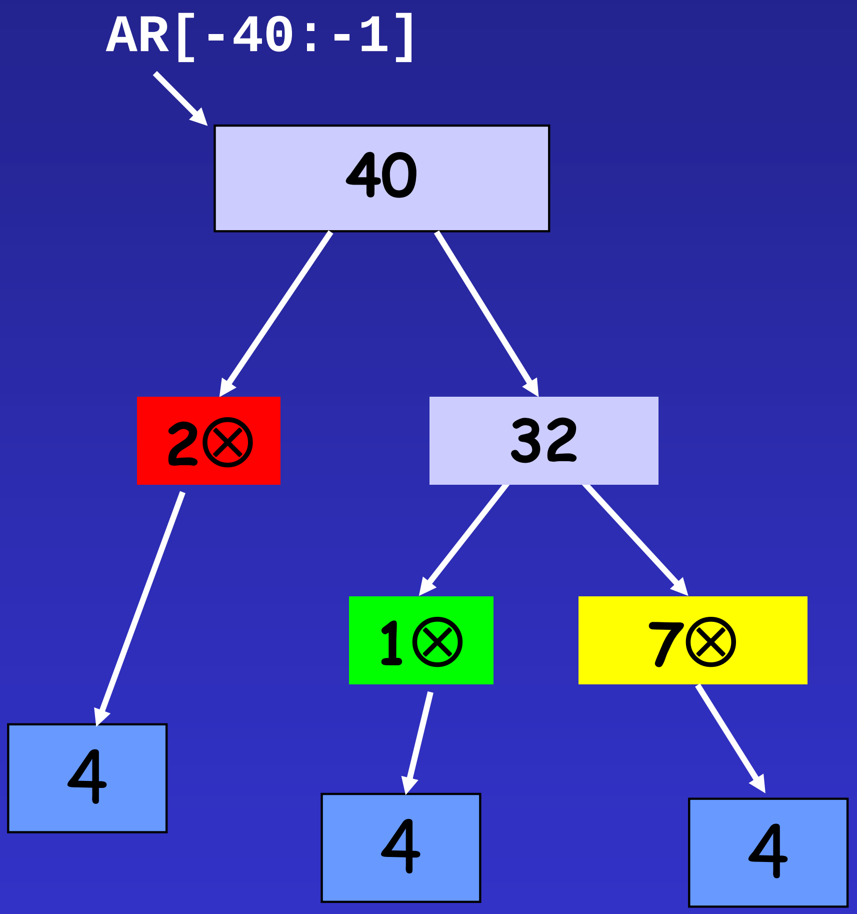


Region for main

ASI: two arrays;
one scalar

IDA Pro
one 8-byte a-loc
one 32-byte a-loc

Aggregate Structure Identification



High level type:

```
struct {
  int a[2];
  int b;
  int c[7];
};
```

ASI: two arrays; one scalar

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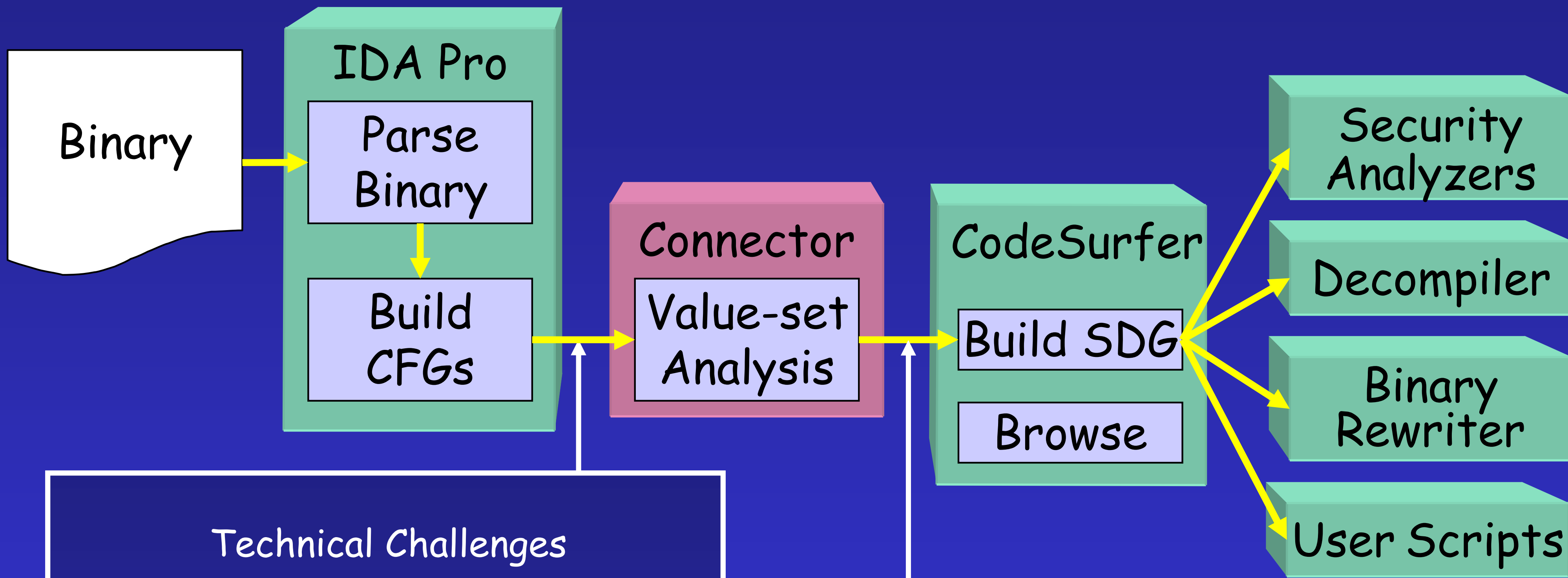

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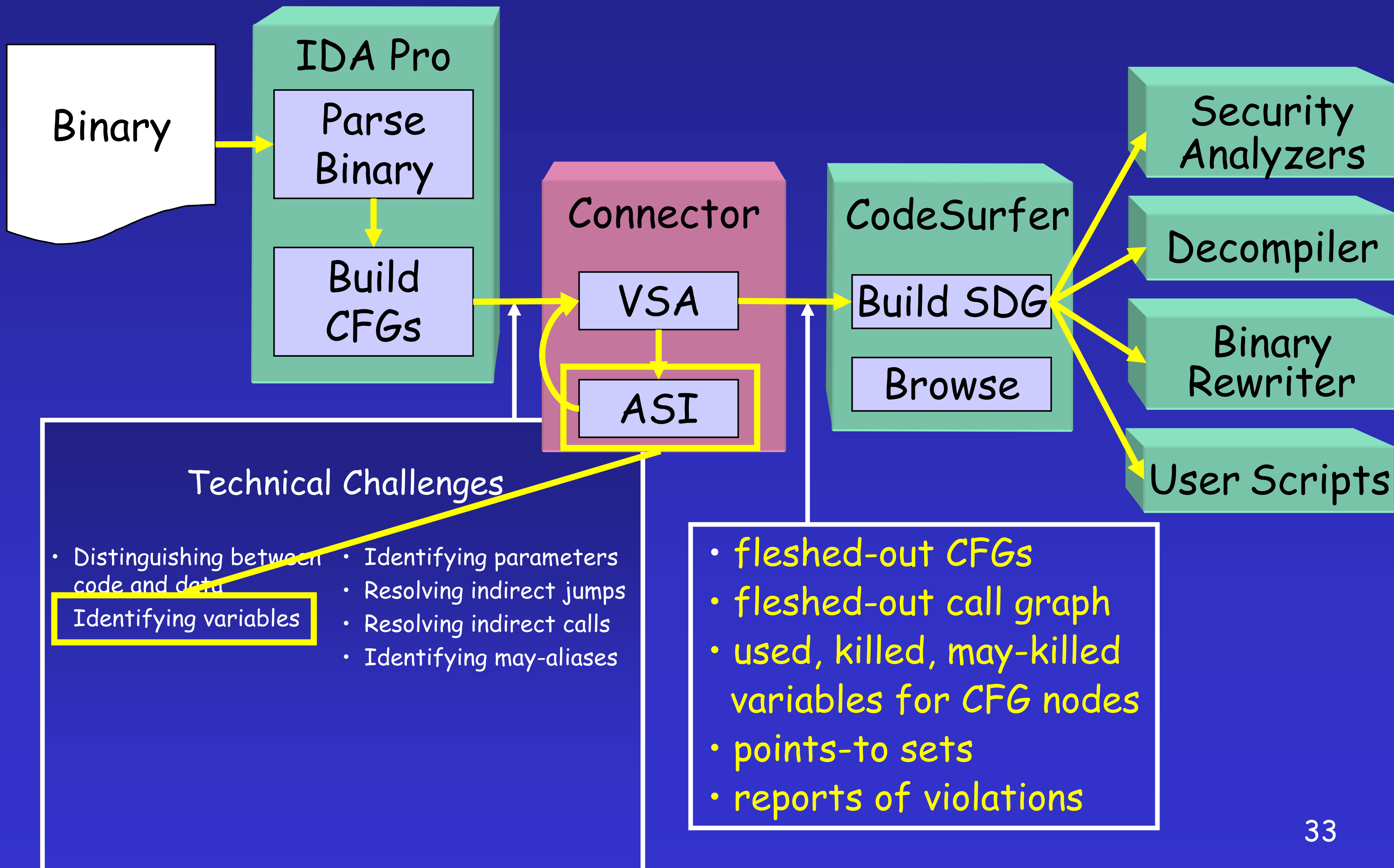

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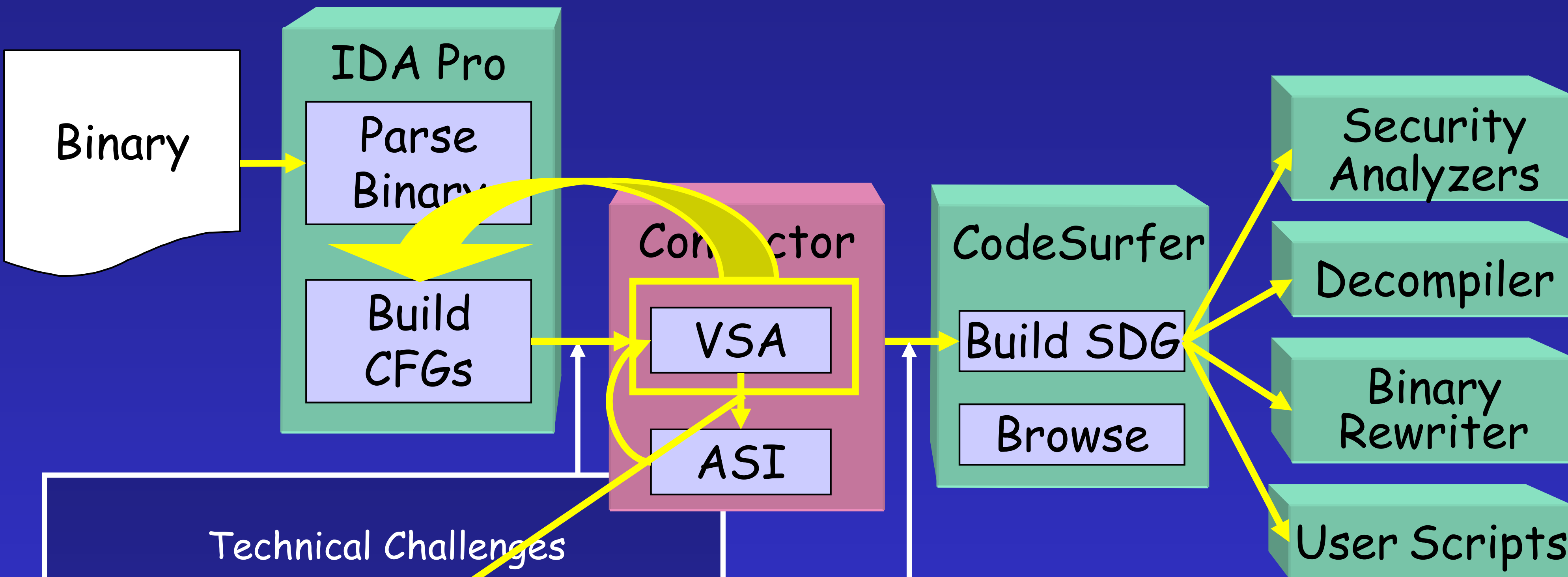

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