CSSV: Towards a Realistic Tool for Statically Detecting All Buffer Overflows in C

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DAEDALUS *project*

Vulnerabilities of C programs

```
/* from web2c [strpascal.c] */
    void foo(char *s)
    {
        while ( *s != ‘ ‘ )
            s++;
        *s = 0;
    }
```

Null dereference

Dereference to unallocated storage

Out of bound pointer arithmetic

Out of bound update

Is it common?

- General belief – yes!
- FUZZ study
  - Test reliability by random input
  - Tens of applications on 9 different UNIX systems
  - 18% – 23% hang or crash
- CERT advisory
  - Up to 50% of attacks are due to buffer overflow

COMMON AND DANGEROUS

CSSV's Goals

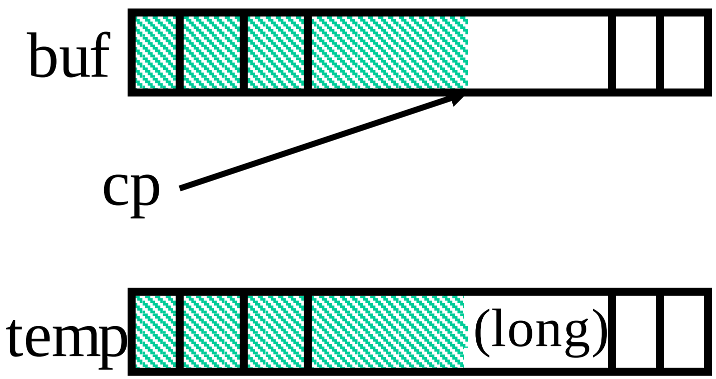
- Efficient conservative static checking algorithm
  - Verify the absence of buffer overflow --- not just finding bugs
  - All C constructs
    - Pointer arithmetic, casting, dynamic memory, …
  - Real programs
  - Minimum false alarms

Complicated Example

```
/* from web2c [fixwrites.c] */
#define BUFSIZ 1024
char     buf[BUFSIZ];

char insert_long(char *cp)
{
     char    temp[BUFSIZ];
     ...
     for (i = 0; &buf[i] < cp ; ++i)
          temp[i] = buf[i];

     strcpy(&temp[i],"(long)");
     strcpy(&temp[i+6],cp);
     ...
```



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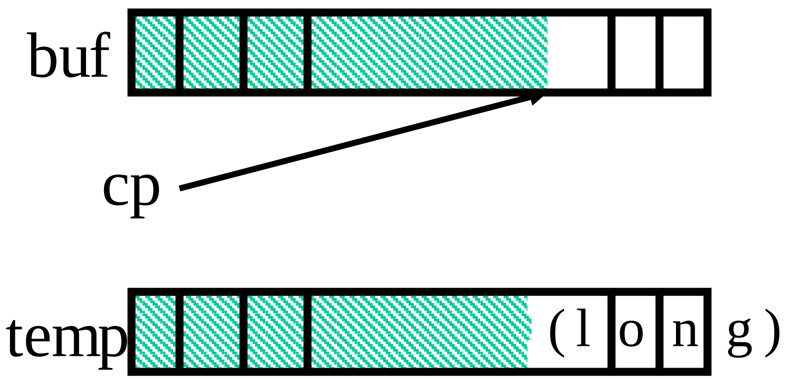

Cleanness is potentially violated:

$7 + \text{offset}(cp) \geq BUFSIZ$

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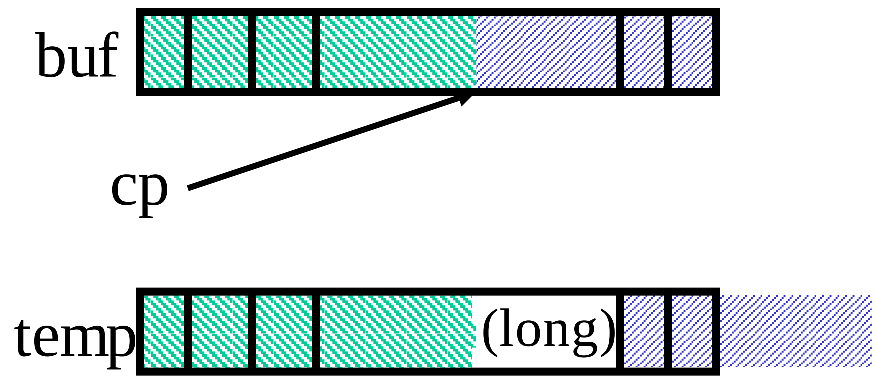


Cleanness is potentially violated:

$offset(cp)+7+len(cp) \geq BUFSIZ$

$7 + offset(cp) < BUFSIZ$

Verifying Absence of Buffer Overflow is non-trivial

```
void safe_cat(char *dst,  int size, char *src )
{
```

$$\left\{ \begin{array}{c} string(src) \wedge string(dst) \wedge \\ (size > len(src)+len(dst)) \Rightarrow alloc(dst+len(dst)) > len(src)) \end{array} \right\}$$

```
  if ( size > strlen(src) + strlen(dst) )
  {
```

$$\{string(src) \wedge string(dst) \wedge alloc(dst+len(dst)) > len(src)\}$$

```
      dst = dst + strlen(dst);
```

$$\{string(src) \wedge alloc(dst) > len(src)\}$$

```
      strcpy(dst, src);
  }
}
```

Can this be done for real programs?

- Complex linear relationships
- Pointer arithmetic
- Loops
- Procedures

- Use Polyhedra[CH78]
- Points-to-analysis
- Widening
- Procedure contracts

Very few false alarms!

C String Static Verifier

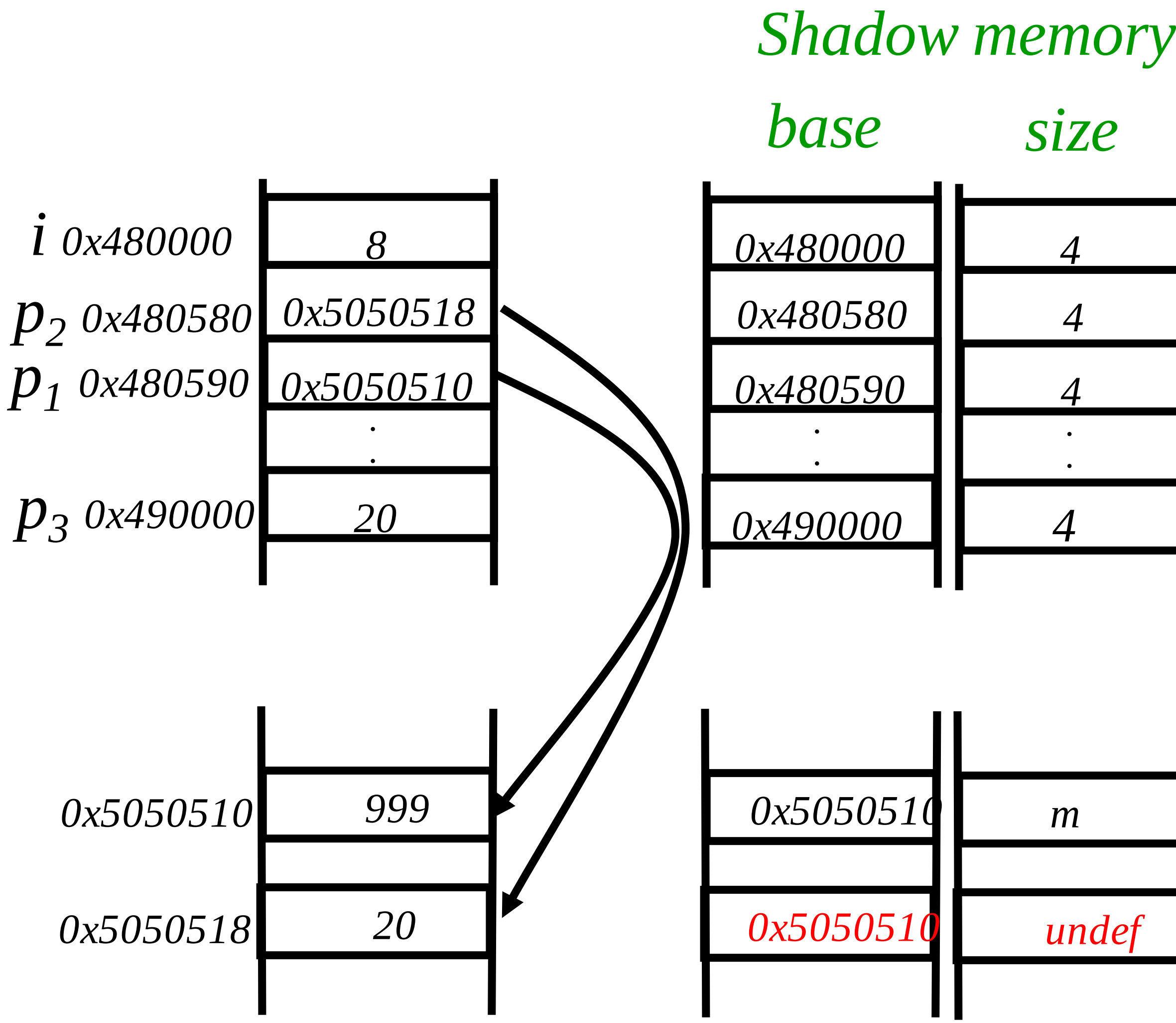
- Detects string violations
  - Buffer overflow (update beyond bounds)
  - Unsafe pointer arithmetic
  - References beyond null termination
  - Unsafe library calls
- Handles full C
  - Multi-level pointers, pointer arithmetic, structures, casting, …
- Applied to real programs
  - Public domain software
  - C code from Airbus

Operational Semantics

$p_1 = alloc(m)$

$p_2 = p_1 + i$

$p_3 = *p_2$

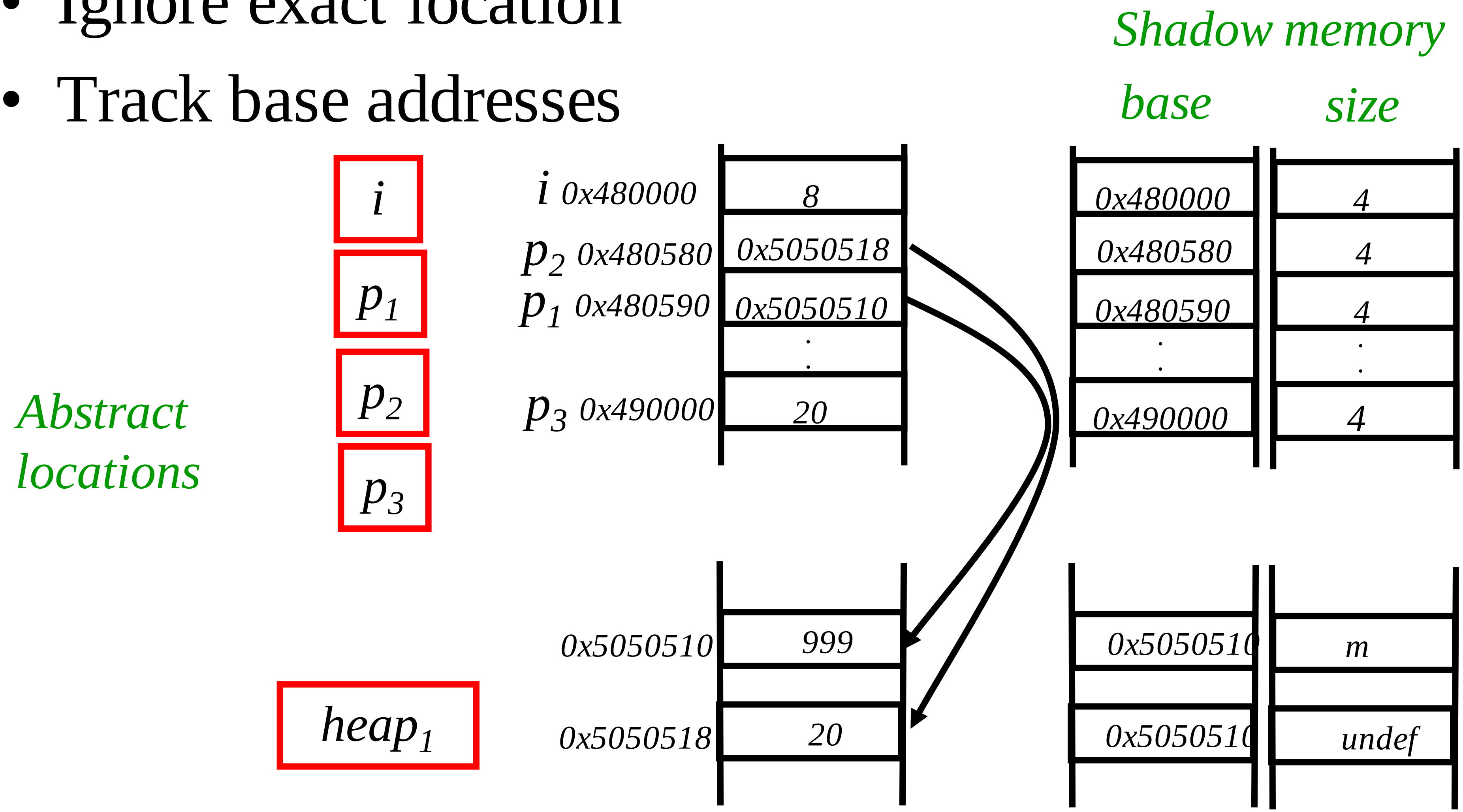


Domain Construction

- Given an abstract domains $D_1, D_2, \ldots, D_k$
- Construct a "composite domain" $c(D_1, D_2, \ldots, D_k)$
- Examples:
  - Cartesian Abstraction
- More later

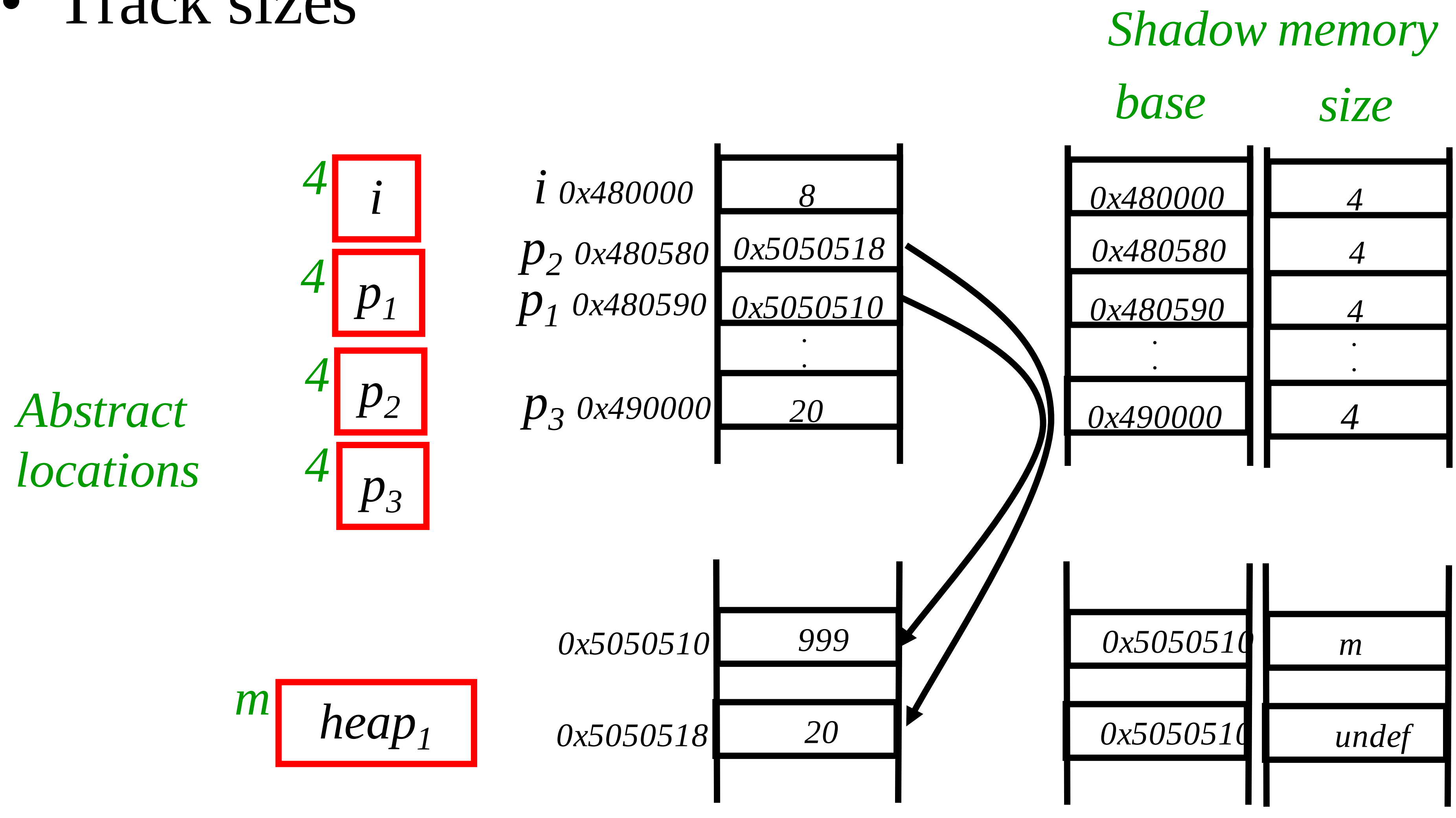
CSSV's Abstraction

- Ignore exact location
- Track base addresses



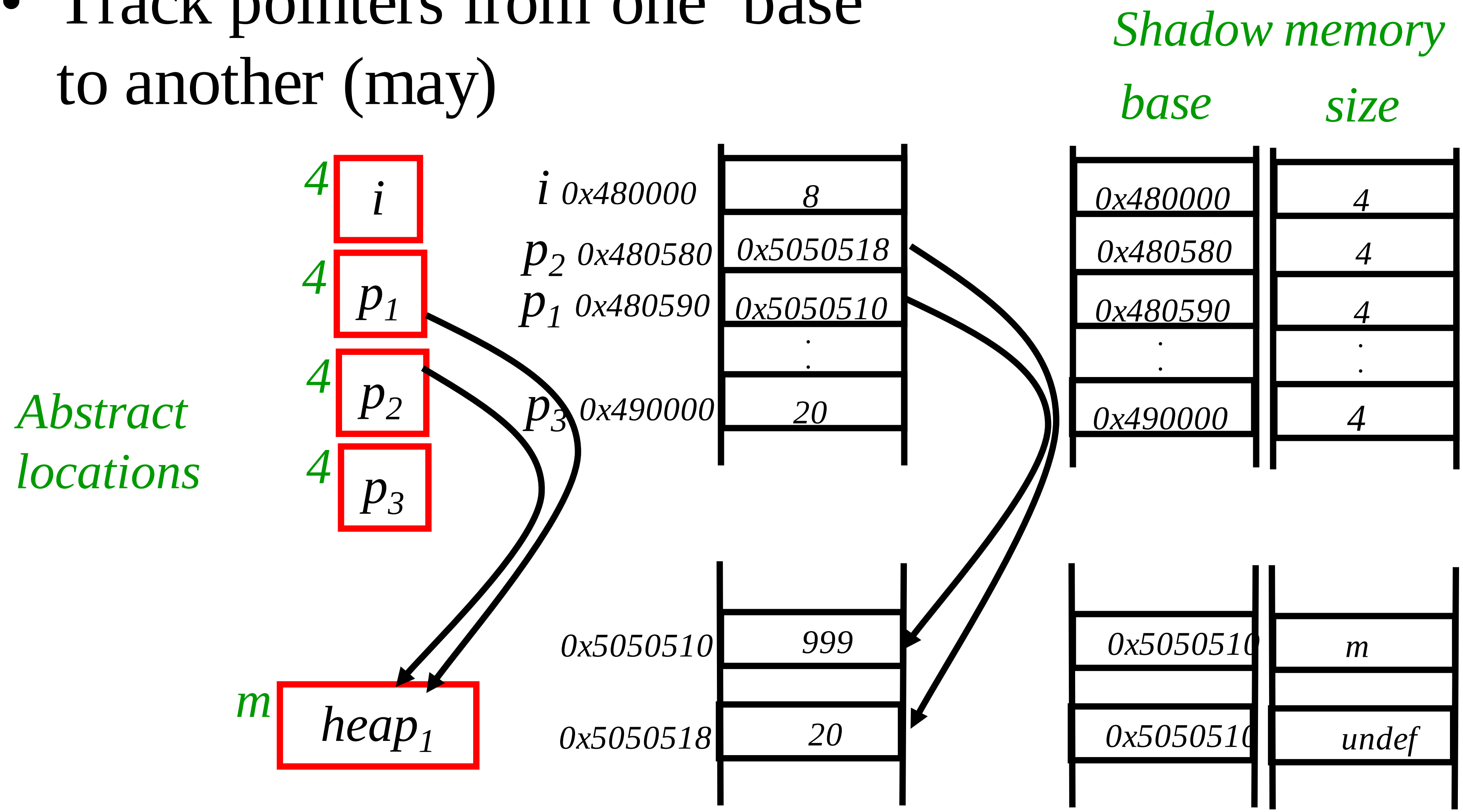
CSSV's Abstraction

- Track sizes



CSSV's Abstraction

- Track pointers from one base to another (may)

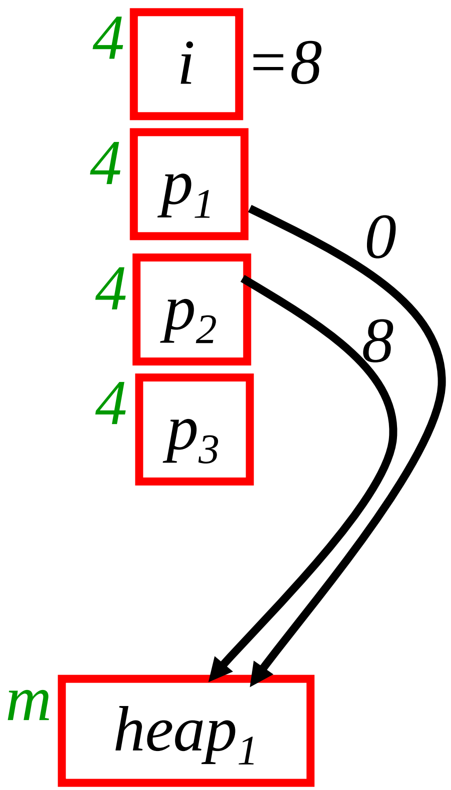


Pointer Validation

- How can we validate pointer arithmetic?

$$p_2 = p_1 + i$$

- Track offsets from origin
- Track numeric values

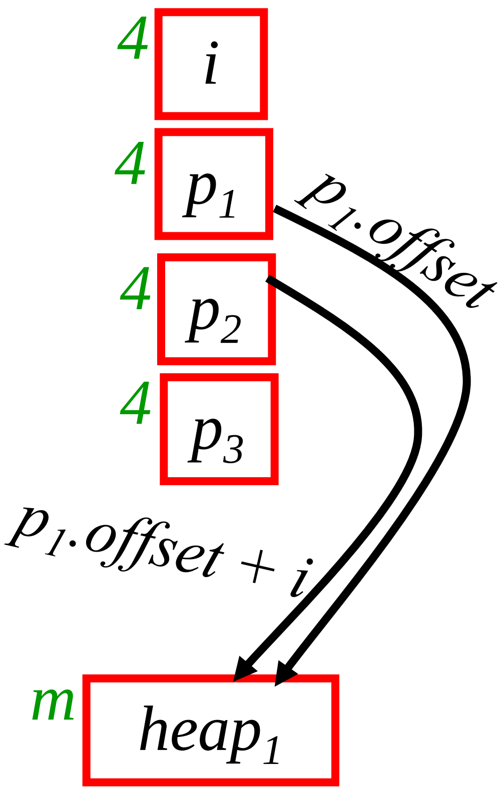


Numeric values are unknown

- Track integer relationships

$$p_2 = p_1 + i$$

$$p_2.offset = p_1.offset + i$$



Validation

- Pointer arithmetic

$$p_2 = p_1 + i$$

$$*p_1.size \geq p_1.offset + i$$

- Pointer dereference

$$p_3 = *p_2$$

$$*p_2.size \geq p_2.offset$$

The null-termination byte

- Many expressions involve the ‘\0’ byte

strcpy(dst, src)

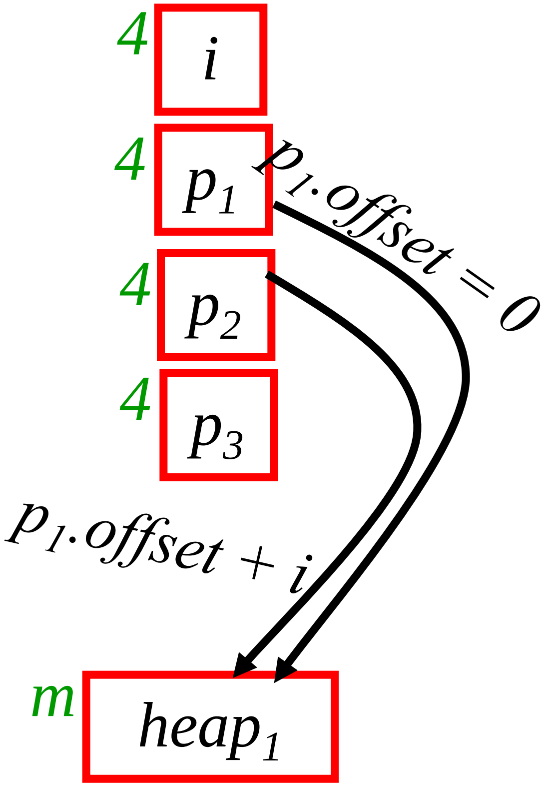
- Track the existence of null-termination
- Track the index of the first one

Abstract Transformers

- Defines the effect of statements on the abstract representation

$p_1 = alloc(m)$

$p_2 = p_1 + i$



Abstract Transformers

- Unknown value

$$p_3 = *p_2$$

$$\left.\begin{array}{ll} p_3 = 0 & *p_2.is\_nullt \wedge *p2.len == p2.offset \\ p_3 = unknown & otherwise \end{array}\right\}$$

Overly Conservative

- Representing infeasible concrete states
- Infeasible pointer aliases
- Infeasible integer variables

Procedure Calls – Contracts

char* strcpy(char* dst, char *src)

requires (string(src) $\wedge$
alloc(dst) > len(src)
)

mod len(dst), is_nullt(dst)

ensures (len(dst) = = pre@len(src) $\wedge$
return = = pre@dst
)

Advantages of Procedure Contracts

- Modular analysis
  - [Not all the code is available]
  - Enables more expensive analyses
- User control of the verification
  - Detect errors at point of logical error
  - Improve the precision of the analysis
  - Check additional properties
    - Beyond ANSI-C

Specification and Soundness

- All errors are detected
- Violation of procedure’s precondition
  - Call
- Violation of procedure's postcondition
  - Return
- Violation of statement’s precondition
  - ...a[i]...

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safe_cat's contract

void safe_cat(char* dst, int size, char* src)

requires *(string(src) ∧ string(dst)*
alloc(dst) == size
)

mod *dst*

ensures *(len(dst) <= pre@len(src)$_e$ +*
pre@len(dst) ∧
len(dst) >= pre@len(dst|)
)

Specification – insert_long()

```
/* insert_long.c */
#include "insert_long.h"
char buf[BUFSIZ];
char * insert_long (char *cp) {
   char temp[BUFSIZ];
   int i;
   for (i=0; &buf[i] < cp; ++i){
      temp[i] = buf[i];
      }
    strcpy (&temp[i],"(long)");
    strcpy (&temp[i + 6], cp);
    strcpy (buf, temp);
    return cp + 6;
}
```

```
char * insert_long(char *cp)
   requires( string(cp) ∧
           buf ≤ cp < buf + BUFSIZ
           )
   mod cp.len
   ensures (
     len(cp) = = pre@len(cp) + 6
           ∧
     return_value = = cp + 6 ;
           )
```

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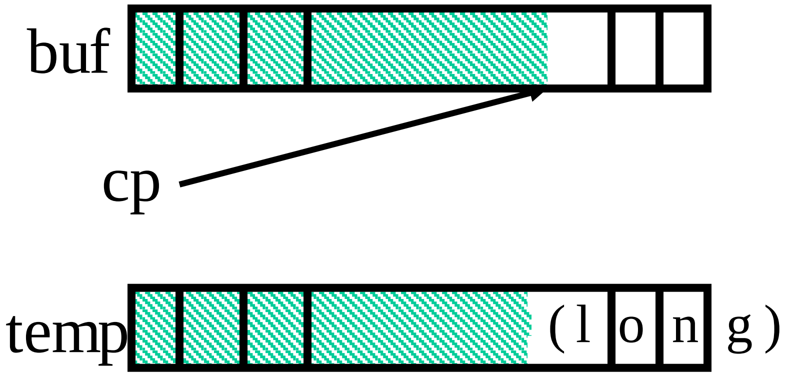

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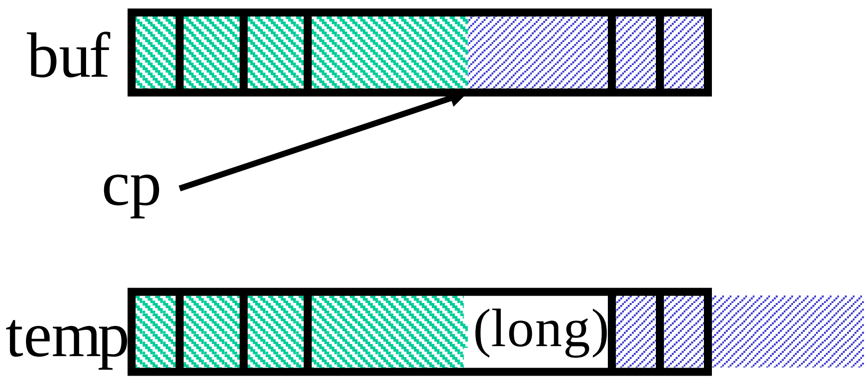

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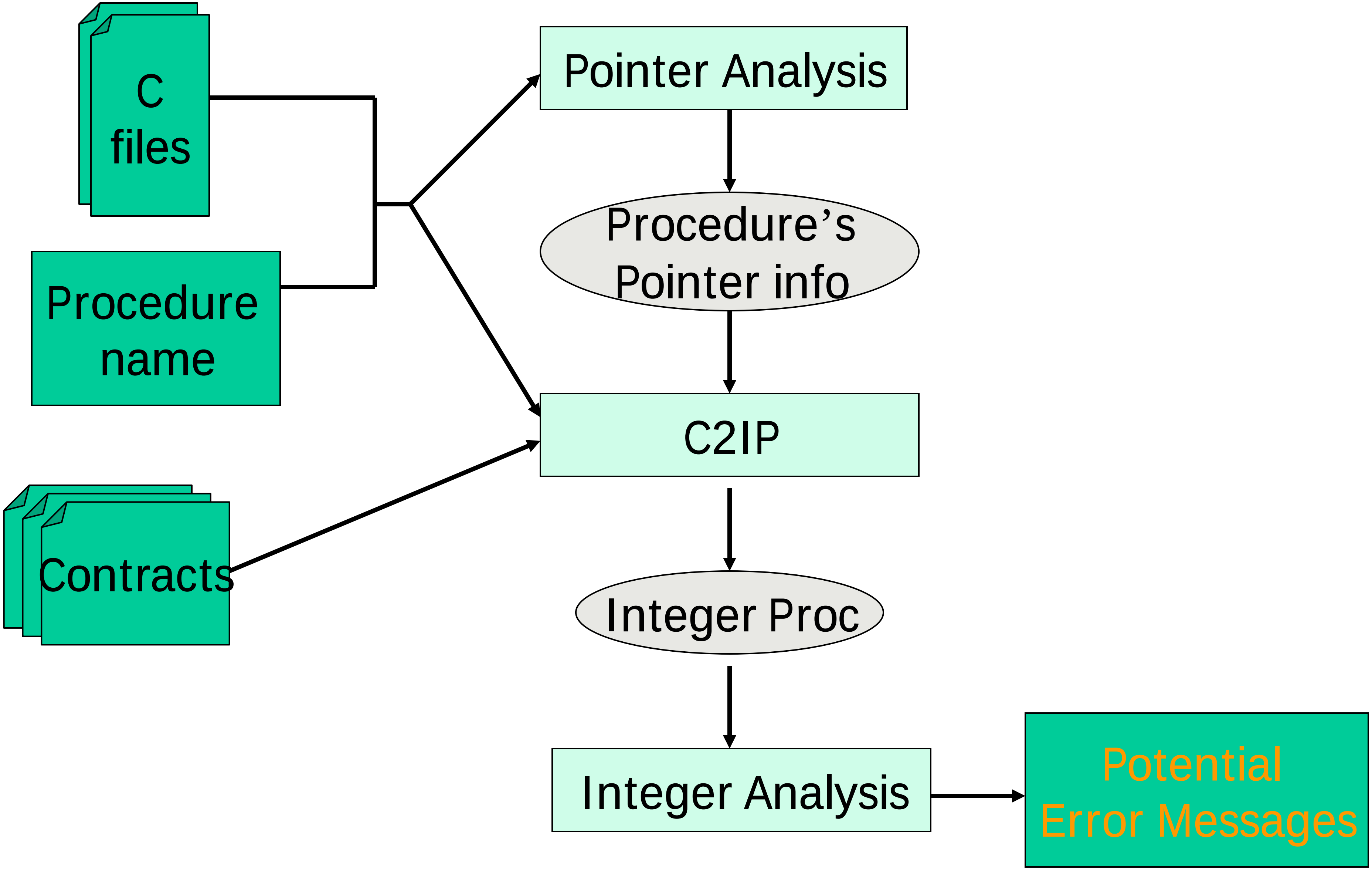
CSSV – Technical overview



Used Software

- ASToolKit [Microsoft]
  - LLVM, Soot
- Core C [TAU - Greta Yorsh]
  - CIL [Berkeley, LLVM]
- GOLF [Microsoft - Manuvir Das]
- New Polka [Inria - Bertrand Jeannet]
  - Apron

CSSV Static Analysis

1. Inline contracts
   - Expose behavior of called procedures
2. Pointer analysis (global)
   - Find relationship between base addresses
   - Project into procedures
3. Integer analysis
   - Compute offset information

Preliminary results (web2C)

Proc	line	coreC line	time (sec)	space (Mb)	errors	FA
insert_long	14	64	2.0	13	2	0
fprintf_pascal_string	10	25	0.1	0.3	2	0
space_terminate	9	23	0.1	0.2	0	0
external_file_name	14	28	0.2	1.7	2	0
join	15	53	0.6	5.2	2	1
remove_newline	25	105	0.6	4.6	0	0
null_terminate	9	23	0.1	0.2	2	0

Preliminary results (EADS/RTC_Si)

Proc	line	coreC line	time (sec)	space (Mb)	errors	FA
FiltrerCarNonImp	19	34	1.6	0.5	0	0
SkipLine	12	42	0.8	1.9	0	0
StoreIntInBuffer	37	134	7.9	21	0	0

CSSV: Summary

- Semantics
  - Safety checking
  - Full C
  - Enables abstractions
- Contract language
  - String behavior
  - Omit pointer aliasing
- Procedural points-to
  - Scalable
  - Improve precision
- Static analysis
  - Tracks important string properties
  - Utilizes integer analysis

Related Projects

- SAL Microsoft
- Splint: David Evans
- Sage: Microsoft
- Brian Hacket static analysis, ICSE’2006
- Vinod Ganapathy: CCS’2013

Conclusion

- 👍 Ambitious sound analyses
- 👍 Very few false alarms
- ⍰ Scaling is an issue
  - Use staged analyses
  - Use modular analysis
  - Use encapsulation