A Theory of Platform-Dependent Low-Level Software

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The memory-safety of a C program often depends on assumptions that hold for some but not all compilers and machines.

Example

```
struct S { void *buf; int    len; };
struct D { void *buf; size_t len; };
...
struct S ss[100];
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struct D* ds = (struct D*)ss;
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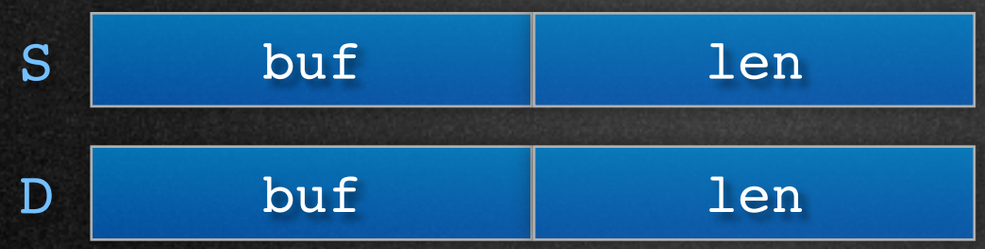

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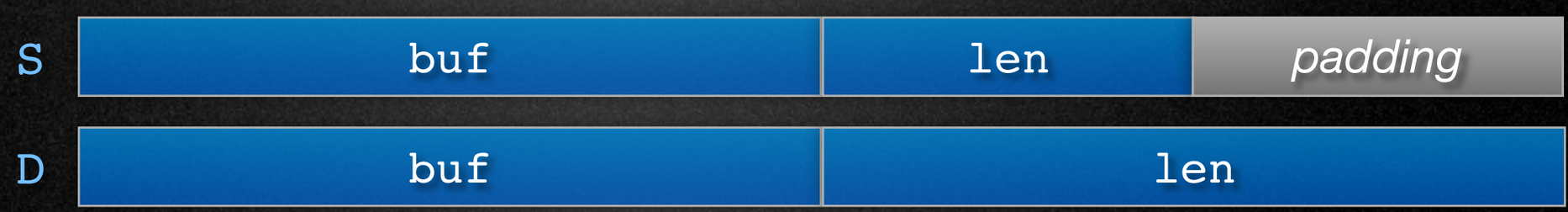

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  - How structs are padded.
  - Sizes of types.
  - Alignment restrictions of the underlying hardware.
- Porting to new platforms is hard:
  - Must identify which code needs to change.

Tool Support is Weak

- Lint-like technology.
- Grep.
- Compiler flags:
  - -Wpadded
  - -Wcast-align

POPL + C = ?

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- Improving C (e.g., *CCured*, *Cyclone*, *Deputy*, *SAFECode*):
  - Assume a particular platform or
  - Make the same assumptions as the underlying C compiler.
- Formal semantics for C-like languages (e.g., *Leroy*, *Norrish*):
  - Omit platform-dependent operators or
  - Model platform-dependent steps as nondeterminism.

This Work

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- Semantics for a C-like language:
  - Explicit notion of platform and platform-dependent steps.
  - Memory-safety is platform-dependent.
- A bug-finding tool:
  - Discovers a class of portability bugs in C programs statically.
  - Does not need physical access to target platforms.

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Formal Semantics

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Overview

- Explicit notion of **platform**.
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- Given a program ***e***:
  - We extract a constraint ***S*** from ***e***.
  - ***e*** is memory-safe on all platforms **Π** described by ***S***.

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- Constraint extraction: type-and-effect system.

$$\Gamma \vdash e : \tau \; ; \; S$$

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Key Theorem

If $\Gamma \vdash e:\tau \; ; \; S$ and $\Pi \models S$

and $\Pi \vdash e \rightarrow^* e'$, then e' is not stuck on Π.

Core Language

- C-like language with many relevant features, including:
  - struct types
  - pointer casts: `(T*)e`
  - address-of-field operator: `&e→f`

Operational Semantics

- Byte-level memory model.
  - `*e` steps to a sequence of ***n*** bytes.
    - ***n*** = size of `e`'s type.
- As in C, pointer casts are unchecked.
  - `(T*)e` steps to `e`.

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Extracting Constraints

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- Most rules are standard:

$$\frac{\Gamma \vdash e_1 : \tau' \; ; \; S_1 \qquad \Gamma \vdash e_2 : \tau \; ; \; S_2}{\Gamma \vdash e_1 ; e_2 : \tau \; ; \; S_1 \wedge S_2}$$

Pointer Cast Constraint

$$\frac{\Gamma \vdash e : \tau_{src}^{*} \; ; \; S}{\Gamma \vdash (\tau_{dest}^{*})e : \tau_{dest}^{*} \; ; \; S \wedge \mathit{subtype}(\; \mathit{layout}(\tau_{src})^{*}, \mathit{layout}(\tau_{dest})^{*} \;)}$$

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- *layout*: a type's in-memory layout
- *subtype*: subtyping of memory blocks

Checking Constraints

$$\Pi \vDash \mathit{subtype}(\ \mathit{layout}(\tau_{src})^{*}, \mathit{layout}(\tau_{dest})^{*}\ )$$

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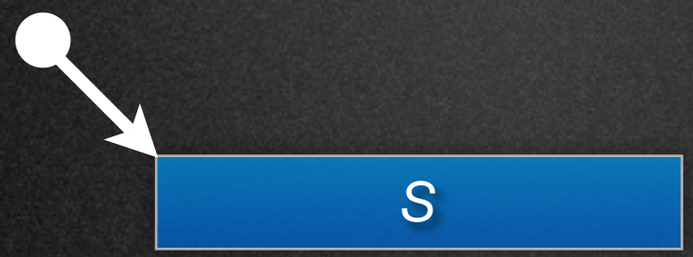
Chandra/Reps
Condit *et al.*

Physical Subtyping

Drop the suffix under a pointer:

$\leq$



Physical Subtyping

Can always subsume to pad bytes:

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- **Theorem**: If $\Gamma \vdash e:\tau \; ; \; S$ and $\Pi \models S$, then $\Pi;\Gamma \vdash e:\tau$.

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- Host/target setup:
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  - Target: platform to which the program is to be ported.
  - Warn only when a cast works on the host but not on the target.
- “Platforms” are defined by us procedurally.
  - 30-50 lines of OCaml per platform definition.

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Case Study

- Ran the tool on Spread:
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- Ran the tool on Spread:
  - Messaging bus for use by distributed applications.
- Found two bugs: one previously unreported.
  - Host: Standard 32-bit/gcc/X86 platform.
  - Target: gcc/LP-64 platform.
  - Zero false positives reported.

Case Study: Tool Output

```
struct scat_element { void *buf; int    len; };
struct iovec        { void *buf; size_t len; };
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```
data_link.c:196: scat_element * ==> iovec *

    Host (Gcc/32-bit/X86):
        Src:  ptr(ptr(b) bbbb)
        Dest: ptr(ptr(b) bbbb)

    Target (Gcc/LP-64):
        Src:  ptr(ptr(b) bbbb----)
        Dest: ptr(ptr(b) bbbbbbbb)
```

Conclusion

- Semantics for a C-like language with unspecified type layout.
- Analysis that finds platform dependencies.
- Some uses:
  - Porting tools.
  - Documentation.
  - Specifications for ***safe*** languages with (partially) unspecified features.

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More in the Paper

- Alignments.
- Complete description of platforms and the constraint language.
- Extensions: arrays, recursive types, conditional execution.
- Detailed tool discussion.

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Thank You!

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