CTSRD

CRASH-worthy Trustworthy Systems Research and Development

Beyond the PDP-11:
Architectural support for a memory-safe C abstract machine

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Why bring the PDP-11 into it?

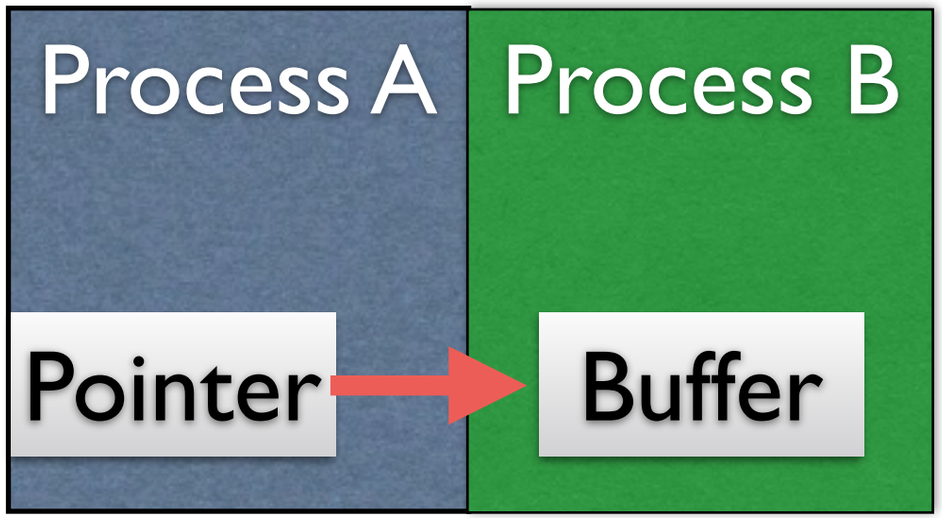
- First target for C
- Flat, byte-addressable memory
- C split memory into objects *purely in software*
- All widely deployed C implementations follow this model

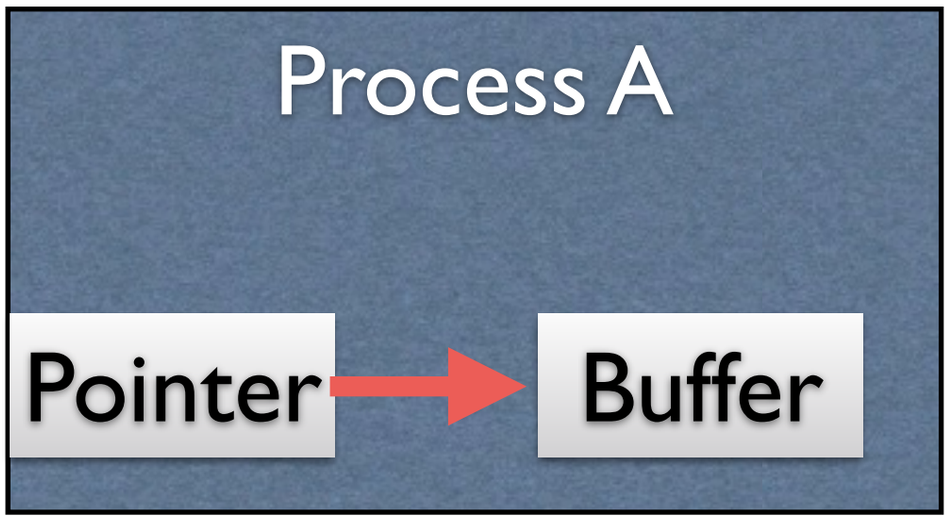
Memory safety for compartmentalisation

- Processes are isolated by hardware (MMU), but expensive
- Fine-grained compartmentalisation needs:
  - Cheap compartments
  - Fine-grained sharing

From compartments to objects

- Sharing requires pointers with enforced bounds and permissions
- Can we use this mechanism for *every* pointer?





The initial CHERI ISA

- All memory accesses via a capability register
- ISA allows reducing capabilities
- Tagged memory protects capabilities

Binary compatibility

More compatible

More safe

n64
Pure MIPS

Hybrid
Some pointers are capabilities

Pure-capability
All pointers are capabilities

The prototype CPU

- 64-bit MIPS-compatible ISA (≈R4000)
- CHERI ISA extensions
- Runs at 100MHz on FPGA
- Full software stack

Real world code

- A lot of C is implementation defined
- Most real C code does interesting things with pointers
- Case study: **`tcpdump`** does most of them (on untrusted data, running as root)

Supporting just the standard isn't enough

Common pointer idioms

- Full list in the paper
- Around 2M lines of C code surveyed
- Thousands of instances found
- *Breaking them is not acceptable!*

Example: The mask idiom

```
// The low bit of an aligned pointer is
// always 0, so we can hide a flag in it
int *set_flag(int *b)
{
   return (int*)((intptr_t)b | 1);
}
```

00x160123123O

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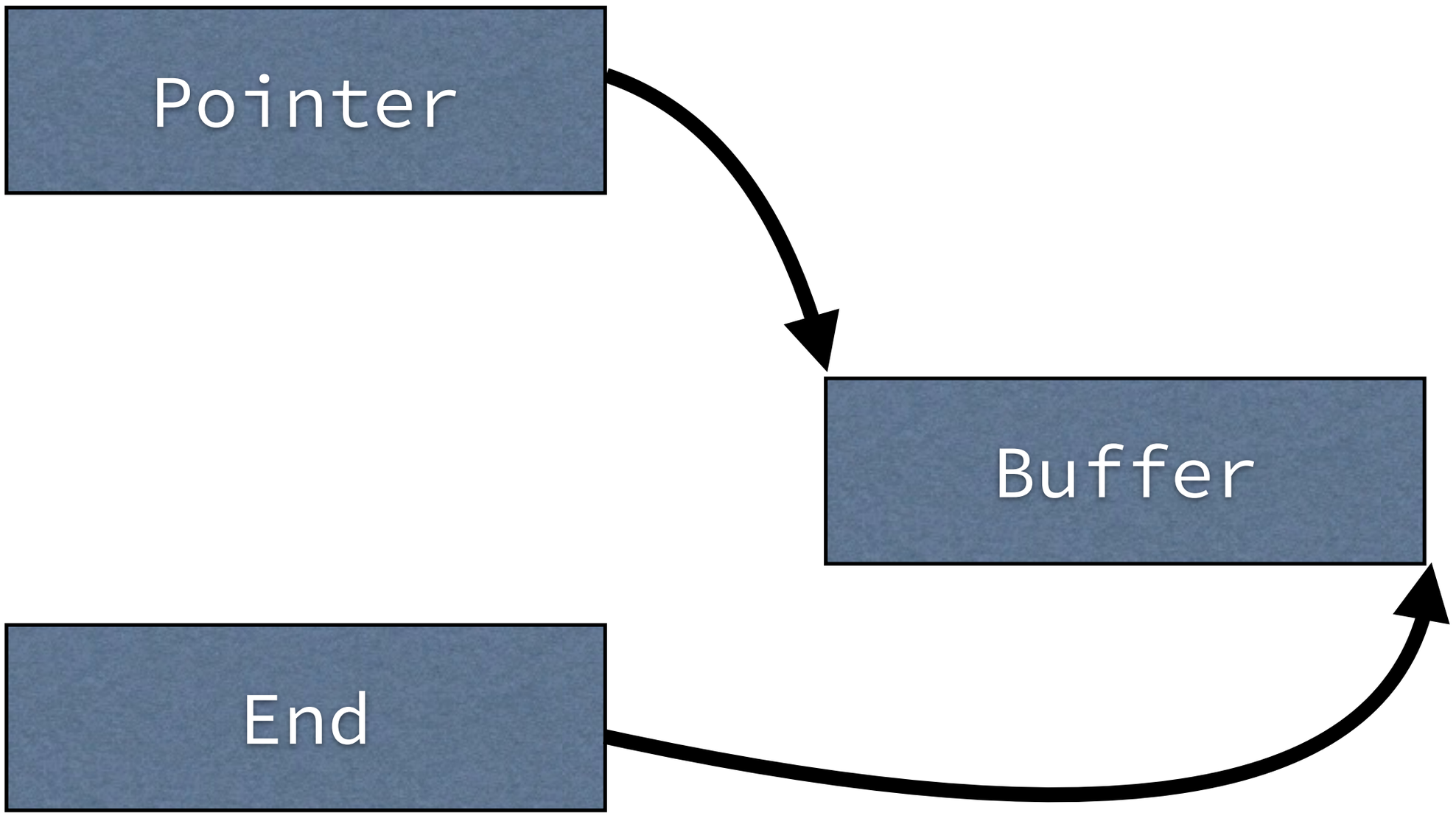
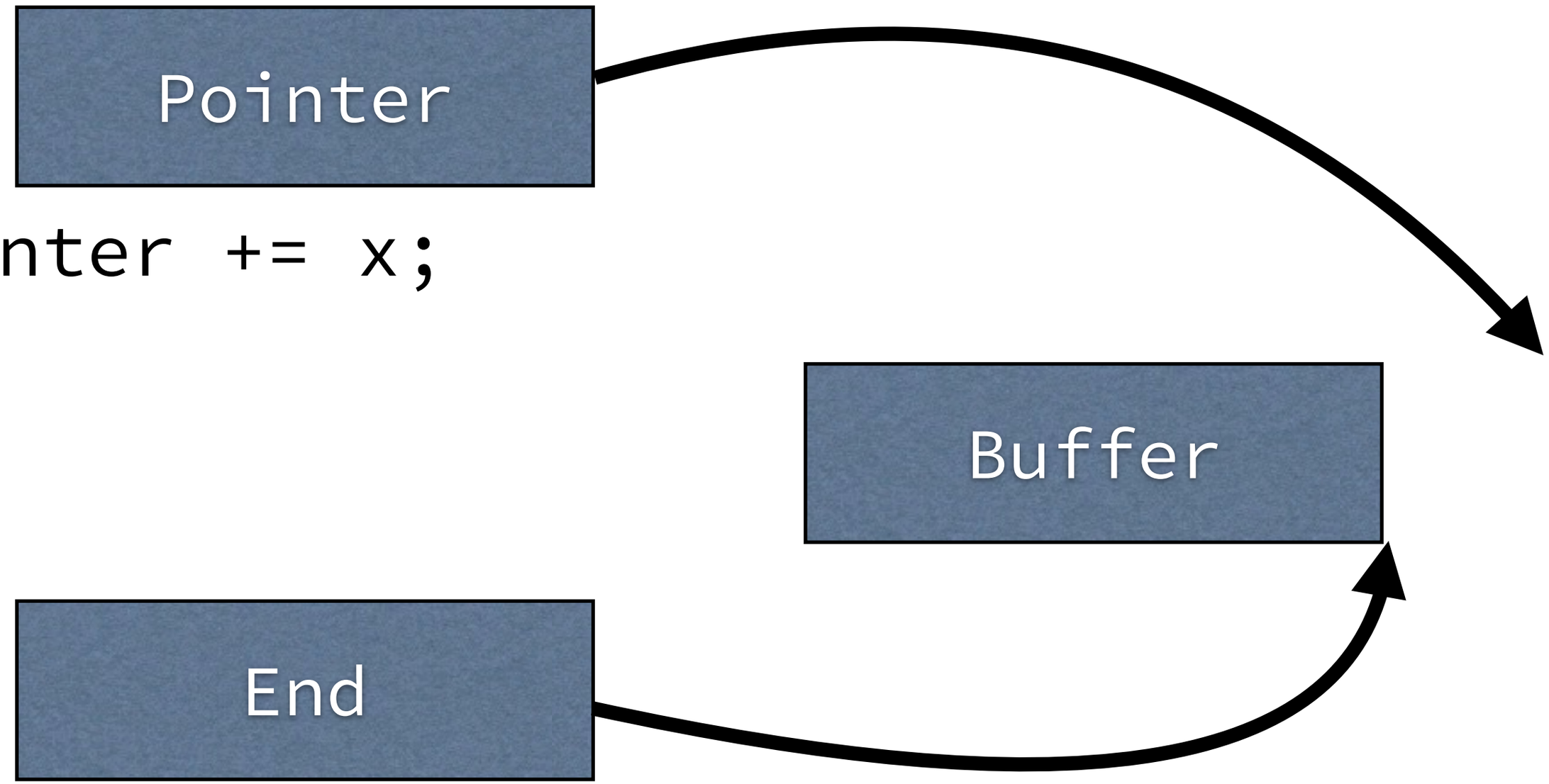
Example: Invalid Intermediates



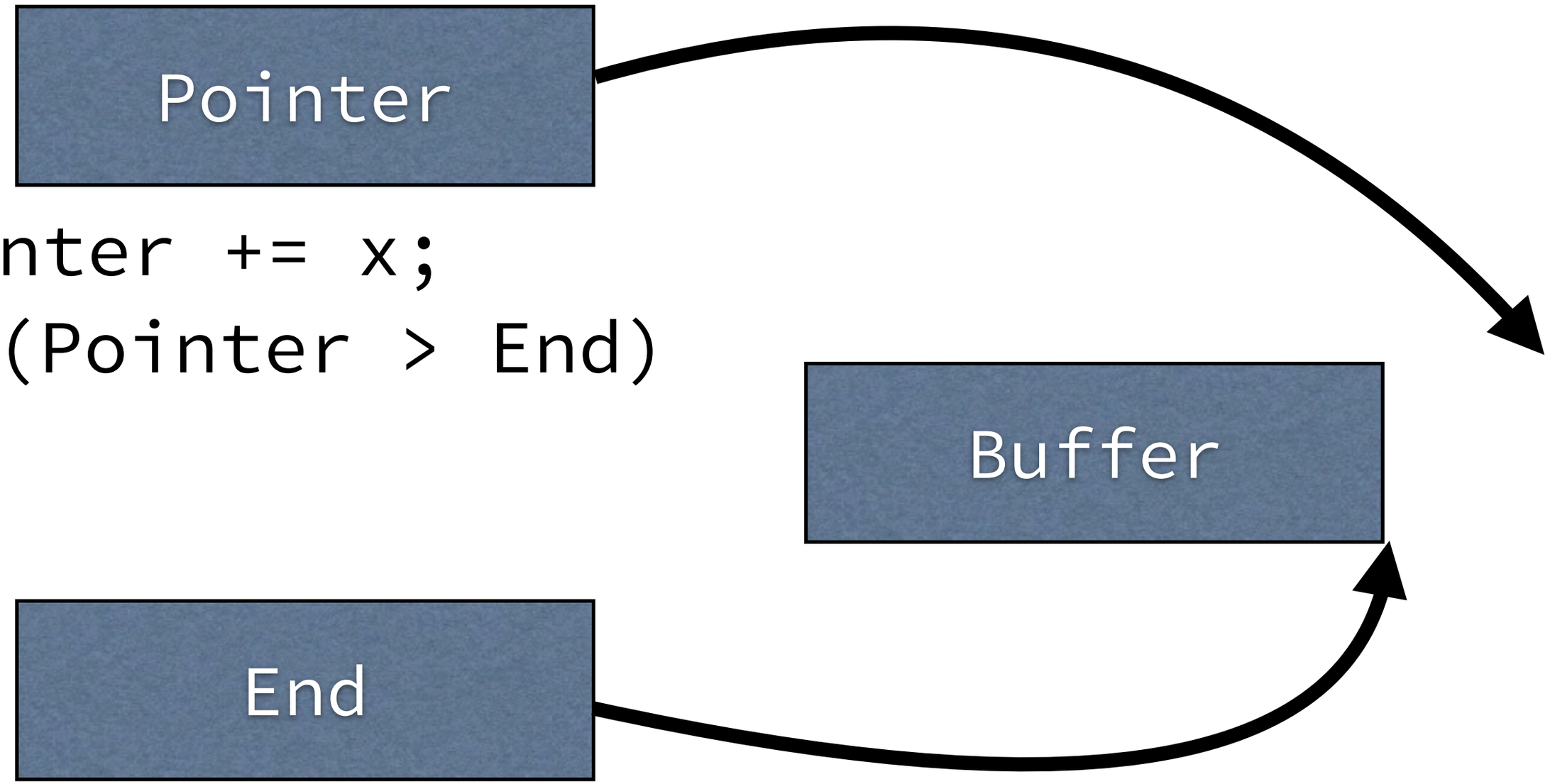
Example: Invalid Intermediates

```
Pointer += x;
```



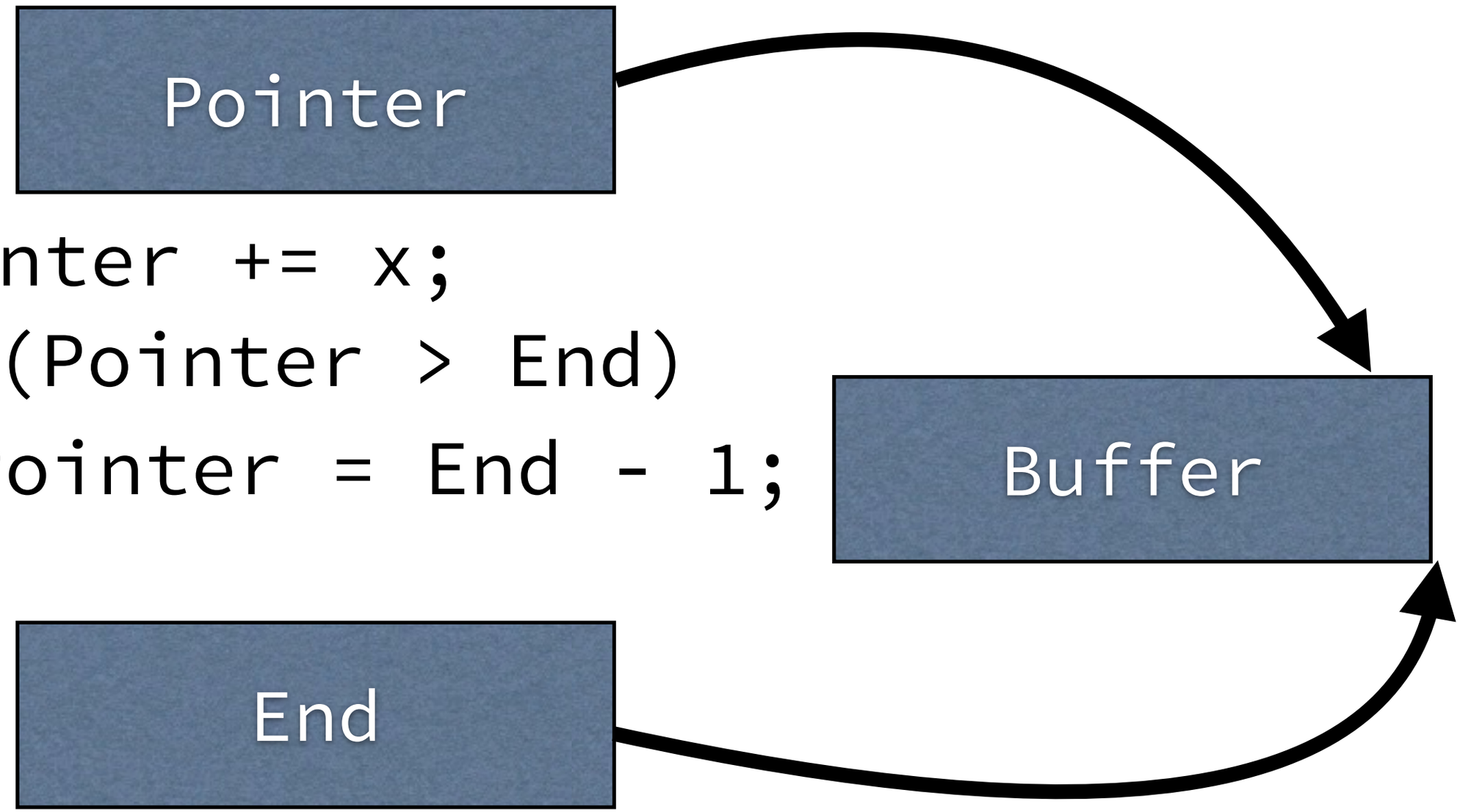
Example: Invalid Intermediates

```
Pointer += x;
if (Pointer > End)
```



Example: Invalid Intermediates

```
Pointer += x;
if (Pointer > End)
   Pointer = End - 1;
```



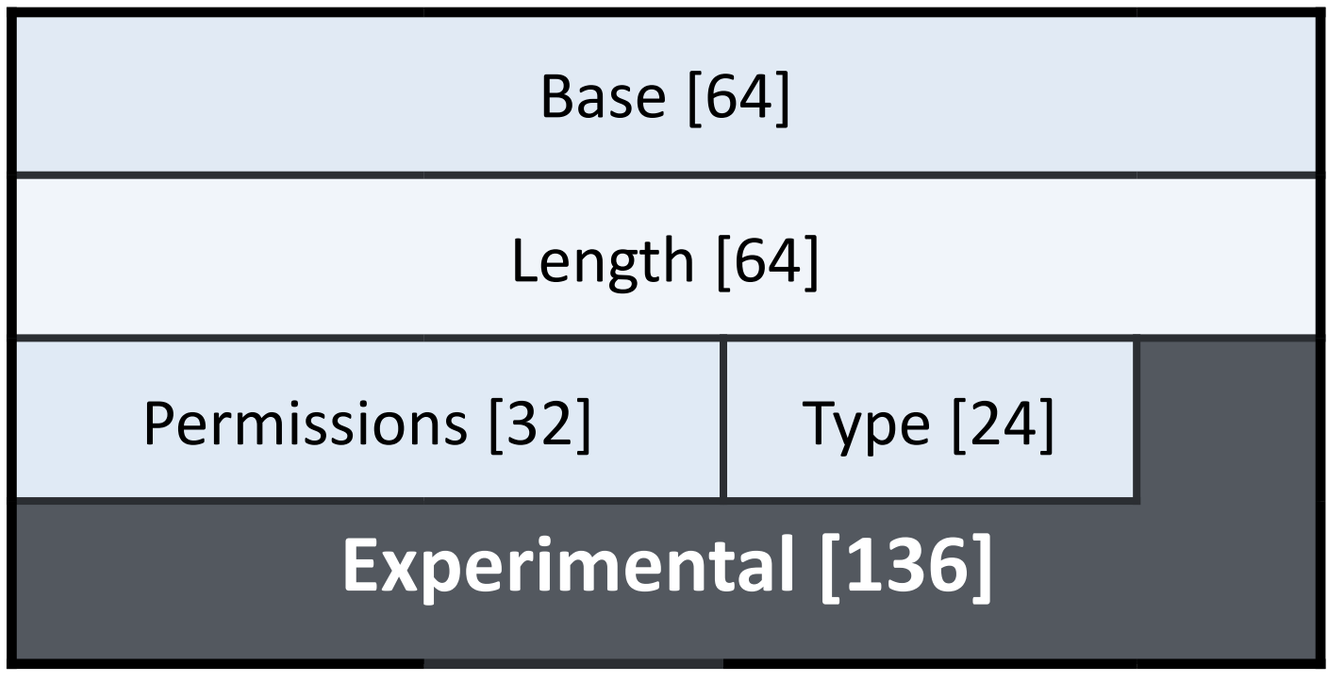
Capabilities

Unforgeable

Monotonic length and permissions

Grant rights

Old CHERI Capabilities:



Fat Pointers

Describe a point

Add metadata

Capabilities + Fat Pointers

Unforgeable

Describe a point

Monotonic length
and permissions

Add metadata

Grant rights

Capabilities + Fat Pointers

Unforgeable

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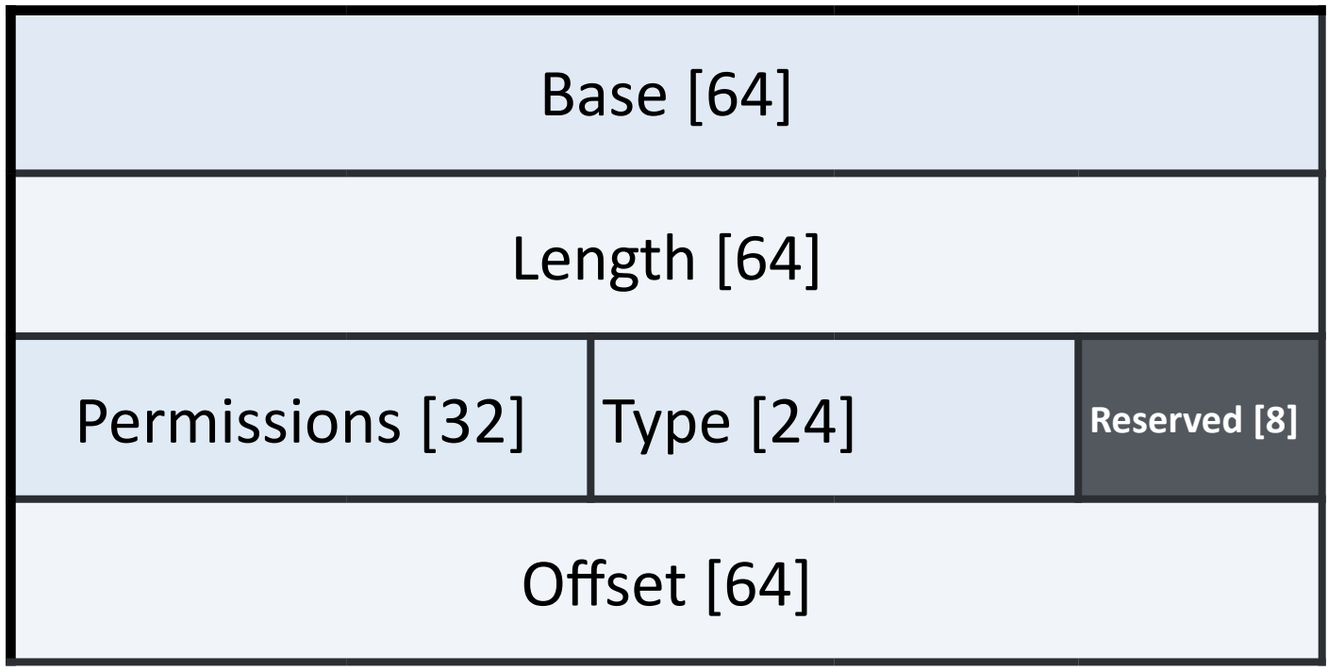
New CHERI Capabilities



- CHERI capabilities extended to include an offset field
- Checks apply only on dereference

It's alive!

- Fully supports real-world C pointer use.
- Negligible overhead in `tcpdump`
- More performance evaluation in the paper

Conclusions

- We have shown that a capability model can provide a memory-safe C abstract machine
- This paves the way for fine-grained compartmentalisation of C programs
- Come and see us at IEEE Security and Privacy for the next part of the story!

http://chericpu.org