CTSRD

CRASH-worthy Trustworthy Systems Research and Development

CheriBSD

Hybrid-capability OS prototype

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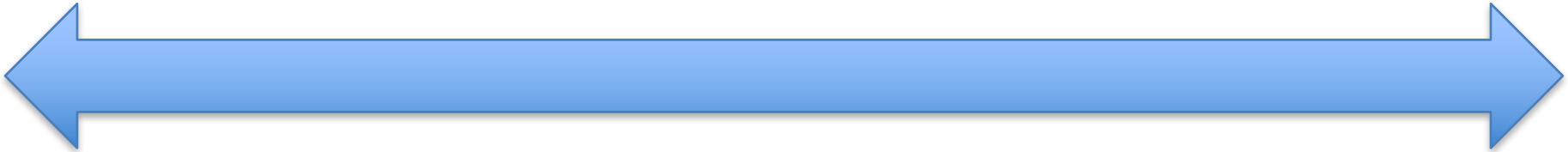
CHERI software models

More compatible — Safer



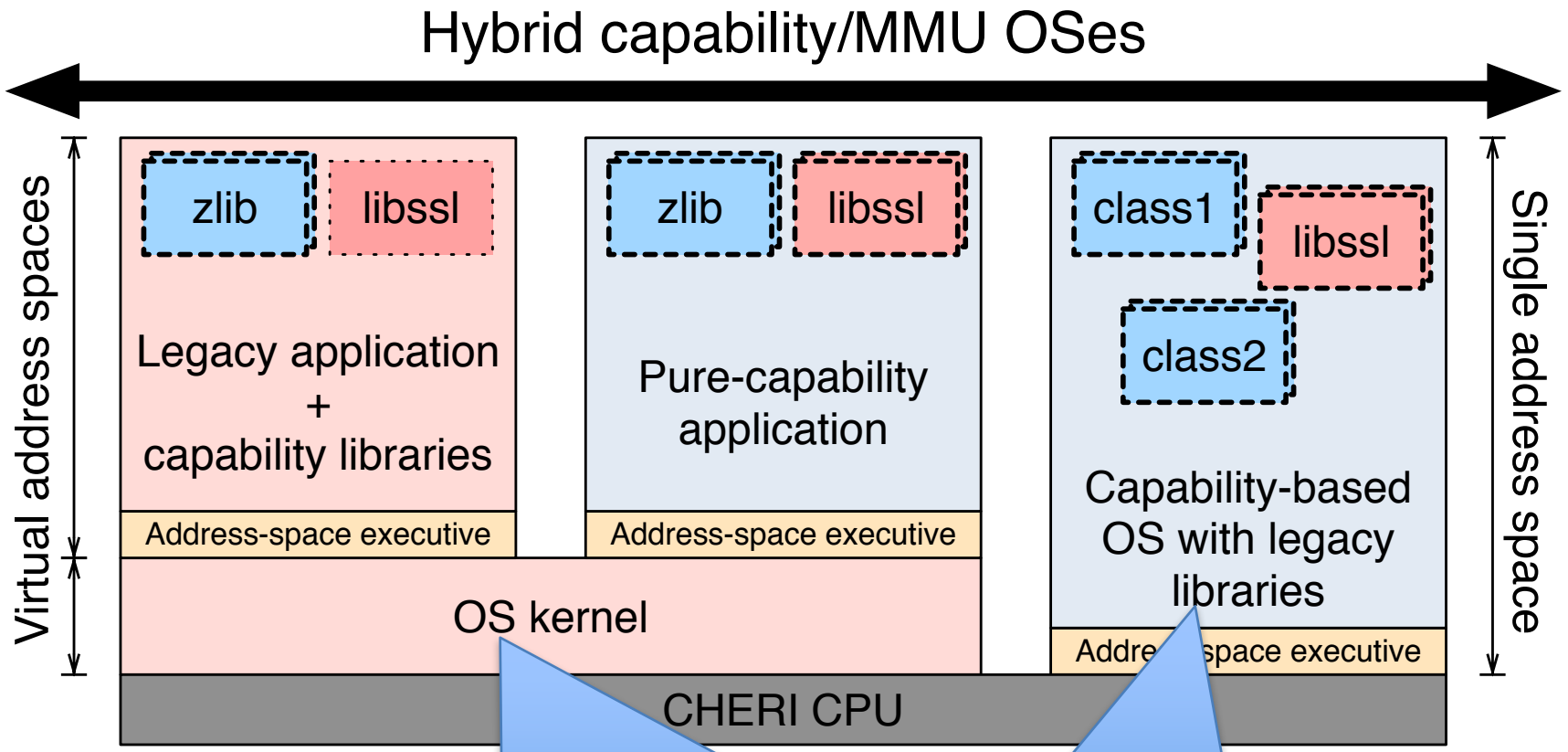
Unmodified
All pointers are registers

Hybrid
Annotated and automatically selected pointers are capabilities

Pure-capability
All code and data pointers are capabilities

- **Source and binary compatibility**: common **C-language idioms,** various **ABIs**
  - **Unmodified code**: Existing n64 code runs without modification
  - **Hybrid code**: e.g., used solely in return addresses, for annotated data/code pointers, for specific types, stack pointers, etc.; n64-interoperable.
  - **Pure-capability code**: ubiquitous data-pointer protection, strong Control Flow Integrity (CFI). Non-n64-interoperable.
- **CHERI Clang/LLVM prototype** generates code for all three

Software deployment models



Hybrid MMU-capability models: protection and compartmentalization within virtual address spaces

Single-address-space systems are possible but not yet our focus

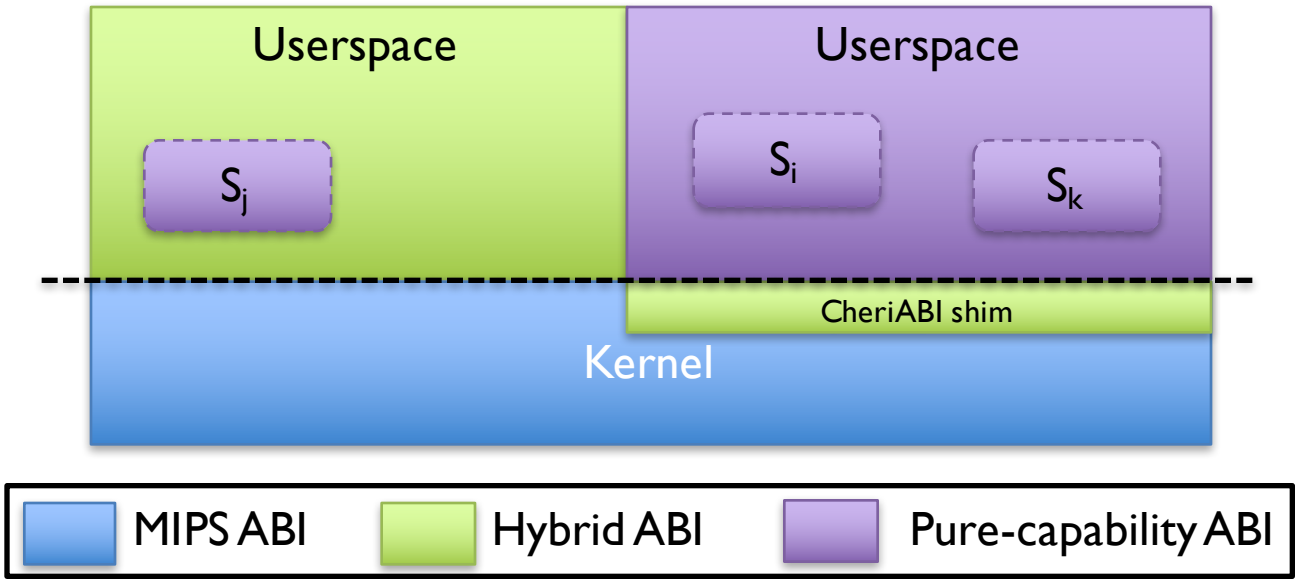
Key software hypotheses

- Viable composition of capability and MMU models for software
  - E.g., CHERI complements paged VM in practical systems
- CHERI capabilities can be usefully applied to program constructs
  - E.g., heap/stack allocations, code pointers, return addresses
  - E.g., kernel-provided memory mappings, static + run-time linking
- Strong binary and source-code compatibility; incremental deployment
  - E.g., selected libraries, applications within a larger system
- Platform for compartmentalization research
  - Libraries/applications are efficiently/easily compartmentalized
  - But also kernel code (in due course)

CheriBSD

- Based on open-source FreeBSD operating system
- "Minimalist" kernel adaptation
  - Process model, VM, debugging, signals support capabilities
  - E.g., thread state includes capability registers
  - E.g., tags preserved for swapped anonymous memory
  - Kernel actually compiled with MIPS, not CHERI, compiler
- Multiple process ABIs: hybrid MIPS and CheriABI
- Fine-grained, in-address-space compartmentalization model
  - Kernel-assisted domain transition, fault handling
  - libcheri object-capability runtime

Multiple process ABIs



- **64-bit MIPS ABI** supports highly compatible hybrid code execution, traditional pointer-based system calls
- **CheriABI** binaries/processes are pure-capability code throughout; system-call interface enforces user model

Demonstration applications

- Pure-capability libraries and applications
  - Pure-capability compilation of all key system libraries and increasing number of commands – e.g., OpenSSL, OpenSSH
  - Strong memory protection for heap, stack; control-flow integrity for minimally modified or unmodified applications
- Library compartmentalization
  - Transparent, efficient sandboxing of security-critical libraries
- tcpdump compartmentalization
  - Fine-grained: multiple domain transitions per packet
- Otherwise (essentially) unmodified userspace

Next directions

- Short-term: complete pure-capability userspace
  - CHERI-aware run-time linking, multithreading
  - Remainder of C (and C++) pure-capability userspace
  - LLDB debugger support
- Short-term: selected capability use and CFI within the kernel
  - E.g., in CheriABI, for user-originated pointers, network stack
- Longer-term: selectively compartmentalized kernel
  - CHERI-based microkernel within CheriBSD kernel
- Longer-term: non-volatile memory + capabilities
  - Semantics for tagged capabilities within filesystem objects

BACKUP SLIDES

Kernel Changes

Component	File	Lines +	Lines -
Machine-dependent headers	19	1424	11
CHERI initialization	2	49	4
Context management	2	392	10
Exception handling	3	574	90
Memory copying	2	122	0
Virtual memory	5	398	27
Object capabilities	2	883	0
System calls	2	76	0
CheriABI	6	2855	0
Signal delivery	3	327	71
Process monitoring/debugging	3	298	0
Kernel debugger	2	264	0