User-level Checkpointing Through Exportable Kernel State

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Flux Project

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http://www.cs.utah.edu/projects/flux

Key Points

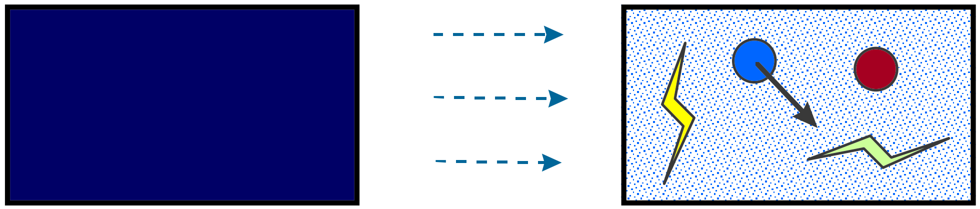
- Always exportable/settable kernel state:
  - Allows interesting user-level OS services
  - Has not been provided before
  - Can be done: Fluke does it
- Flexible checkpointing is an example service

Visible Kernel State

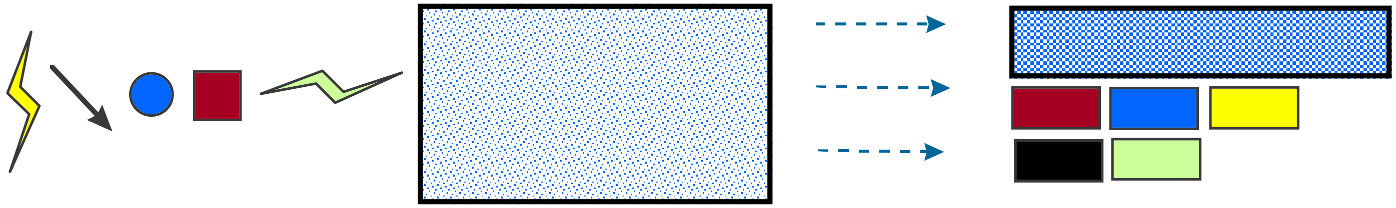
- State exported from or imported to kernel
  - Encapsulated in kernel objects, e.g. threads, ports, ...
- State must *always* be available
- Enables user-level services
  - Process migration, distributed memory, debugging, memory management
  - Checkpointing

Checkpointing: Key Issues

- Find the associated kernel objects



- Extract state from those objects



Checkpointing: The Rest

- Pickle the object state
- Save it
- Bring it back and re-create the target

Sample Kernel Object State

- Thread State
  - Registers
  - IPC state
  - Exception handlers
  - References:
    - Scheduler thread
    - IPC Client
    - IPC Server
    - Address space

- Memory Map State
  - Offset in source
  - Size
  - Start address
  - Protection
  - References:
    - Source space
    - Address space

Hasn't This Been Done?

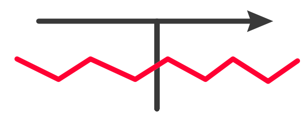
- Amoeba
  - Restrictions on when export is feasible,
    e.g., not during IPC operations
- Mach
  - Restrictions on when export is feasible,
    e.g., not during long-term IPC operations
- V++ Cache Kernel
  - Strict ordering restrictions on export,
    e.g., all "dependent" objects *must* be exported

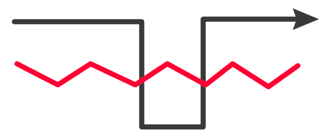
How Fluke Does It

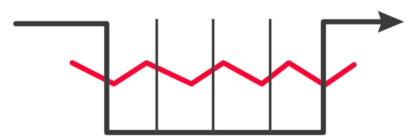
- All necessary kernel state is in objects
  - All implicit kernel state is re-createable
- All operations on objects *appear* atomic
  - Hides implicit kernel state
  - Simplifies object state

Atomic & Restartable Operations

- Atomic operations
  - avoid intermediate state
- "Short" operations
  - undo changes if interrupted
- "Long" operations
  - break into valid intermediate states







Status

- Implemented on x86 PCs
- Checkpointer checkpoints and restores arbitrary subsystems
- Kernel hosts many user-level services
  - Virtual memory, debugging, process management
  - Many Unix utilities including GCC
- Expected release within 2 months

Conclusion

- Cleanly Visible Kernel State:
  - Enables user-level OS services
  - Is tricky to provide
  - Is feasible - Fluke does it

More papers on Fluke at OSDI'96