Kernel Support for User-Level Threads on L4

Diplomverteidigung

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Outline

- Motivation
- Design Goals
- Achievements
- Details
  - Activation Messages
  - Deschedule Blocking Threads
- Conclusions
- Outlook
Motivation

Multiple Concurrent Activities – Threads:
- independent execution
- efficient communication
Multiple Concurrent Activities – Threads:

- independent execution
- efficient communication

Kernel-Level Threads:

- Preemptive Scheduling
- Blocking Operating-System Services

User-Level Threads:

- User-Controlled Per-Thread Resources
- Efficient Communication and Thread Management
Combine the Benefits

- Optimize kernel-level threads, or
- enhance user-level threads.

Enhance User-Level Threads

- First-Class User-Level Threads
- Add Kernel Support
- Use Kernel Thread(s) as Virtual (Multi-)Processor
Design Goals

- High Performance for User-Level Threads
- User-Level Threads on Pageable User-Controlled Resources
- Preserve Performance of Kernel-Level Threads
- Preserve Minimality of the Kernel
- L4 API Compatibility: Relaxed
  - for applications using user-level threads
  - for legacy applications
Which Functionality is Needed?

- **Running Threads**
  - forward progress
  - cooperative thread switch
  - preemptive thread switch

- **Blocking Threads: IPC**
  - atomic send-to-receive switch
  - zero timeout
  - fairness on open wait
Which Functionality is Needed?

- Running Threads
  - forward progress
  - cooperative thread switch
  - preemptive thread switch
- Blocking Threads: IPC
  - atomic send-to-receive switch
  - zero timeout
  - fairness on open wait

What is needed for user-level threads?
Achievements

Which Functionality is Needed? for UL Threads

- Running Threads
  - forward progress
  - cooperative thread switch
  - preemptive thread switch

- Blocking Threads: IPC
  - atomic send-to-receive switch
  - zero timeout
  - fairness on open wait

What is needed for user-level threads?

yes  efficient  possible
Achievements

Which Functionality is Needed?

- Running Threads
  - forward progress: yes
  - cooperative thread switch: efficient
  - preemptive thread switch: possible

- Blocking Threads: IPC
  - atomic send-to-receive switch: Global or Local
  - zero timeout: relaxed
  - fairness on open wait: relaxed

What is needed for user-level threads?
Achievements (2)

Per-Thread Data in L4:
- Thread Control Block (TCB)
- Kernel Memory
Achievements (2)

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Moving Per-Thread Data to User Level:
- data becomes untrusted
- user-level dispatcher code
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Interaction Between Kernel and Dispatcher:
- on preemptive thread switch, and
- to deliver IPC messages
Dispatcher Code

Dedicated Dispatcher Thread:
+ no kernel extensions
− costly preemptive thread switch
− extra kernel thread

Dispatcher Code on Virtual Processor:
+ inexpensive preemptive thread switch
+ no extra kernel thread
− requires kernel extensions
Occupied Virtual Processors
Occupied Virtual Processors

When?

- on blocking global communication
- on long-running system calls
Achievements (4)

Occupied Virtual Processors

When?
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Issues:
- forward progress
Achievements (4)

Occupied Virtual Processors

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Issues:
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Solutions:
- use multiple virtual processors
- deschedule the invoker
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Activation Messages

Move Ready-to-Run Threads to Another VP

- moveable user-level threads
- local thread IDs
- blocking user threads $\leq$ number of VPs
- local communication at user level
Activation Messages

Move Ready-to-Run Threads to Another VP

- moveable user-level threads
- local thread IDs
- blocking user threads \( \leq \) number of VPs
- local communication at user level
- notification about blocking/unblocking of VPs

Activation Messages
Activation Messages (2)

When to Send?
- on switch to receiver, or
- on timer interrupt, or
- on ready list enqueue/dequeue operations

How to Send?
- nested IPC, or
- extra sender role

Where to Send?
- to a virtual processor, or
- to a dedicated dispatcher thread
Activation Messages (2)

When to Send?
- on switch to receiver, or performance
- on timer interrupt, or
- on ready list enqueue/dequeue operations

How to Send?
- nested IPC, or
- extra sender role

Where to Send?
- to a virtual processor, or
- to a dedicated dispatcher thread
When to Send?
- on switch to receiver, or performance
- on timer interrupt, or IPC chains, ex_regs
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Activation Messages (2)

When to Send?
- on switch to receiver, or performance
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- on ready list enqueue/dequeue operations

How to Send?
- nested IPC, or influences regular IPC
- extra sender role

Where to Send?
- to a virtual processor, or (minimality)
- to a dedicated dispatcher thread
Activation Messages (3): Invoking IPC

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Activation Messages (3): Invoking IPC

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Activation Messages (3): Invoking IPC

"Thread 1 blocks."

"Thread 1 blocks."

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Activation Messages (3): Invoking IPC

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Activation Messages (4): Receiving IPC

Diagram showing the interaction between a Caller Task and a Server Task for receiving IPC.
"Thread 1 unblocks."

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Benefits of User-Level Threading Fully Operative
  • Efficient Local Communication
  • Flexible Per-Thread Resources
User Threads can use L4 Functionality
  • Invoking IPC Calls
  • Receiving IPC Calls
Preserved Performance
Preserved Minimality
Activation Messages (6): Limitations

- Separated Local/Global Thread IDs
- Separated Local/Global Communication
- Limited Number of Concurrent Global IPCs
- No Different Priorities
- Restricted Scheduling Fairness
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Deschedule Blocking User-Level Threads

1. User-Level Thread Invokes IPC
   - deschedule invoking thread
   - save blocking state at user level

2. Partner Replies
   - check if reply is valid
   - deliver the message
Deschedule Blocking User-Level Threads (2)

Zero Timeouts:
- dispatcher needs time
- partner thread does not trust the dispatcher

Fairness on Open Wait:
- Sender Queue
  - entirely in trusted memory
  - self-dequeueing
- Sender Information in the Receiver’s Memory
- Wakeup Signals

Not Applicable.
Conclusions

Pageable Resources

Asynchronous Buffered IPC

Intra-Task IPC Without Timeouts

Legacy L4 IPC

Zero Timeouts

Synchronous Unbuffered IPC

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Summary

- investigated methods for user-level threading on L4
- proposed an $N : M$ threading model
- kernel part implemented and working

Future Work

- User-Level Thread Package
- Delayed Preemptions
- Applications
L4 Functionality

Inter-Process Communication (IPC):
- Synchronous and Unbuffered
  - No Buffers in the Kernel
- Zero Timeouts
  - Enforce Trust Relations
- Atomic Send-to-Receive Switch
  - Guarantee Functionality
Client-Server Trust Relations:

- Client Trusts the Server
- Server Guarantees Functionality

Achieved by:

- IPC Call with Atomic Send-to-Receive Switch, and
- Reply with Zero Timeout.
L4 Functionality (3)

Fairness:
- Multiple Blocking Senders
- Receive from Any Thread
- Which Sender Comes First?

Progress:
- Thread States: Running or Blocking
- No Starvation of Running Threads
Dispatcher Code on VP

Entry Points, Asynchronous Events

1. set asynchronous timeout
2. timeout triggers
3. save (part of) the VP state
4. resume execution at entry point
5. perform thread switch

Issues:

- save state area
- lost preemption signals
- kernel cannot wait for user-level code