Asynchronous Abstract Machines

Anti-noise System Software for Many-core Processors

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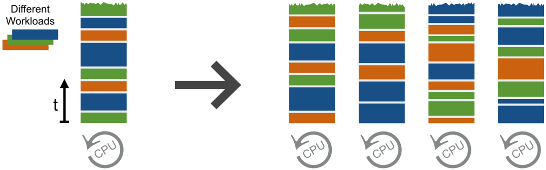
Motivation

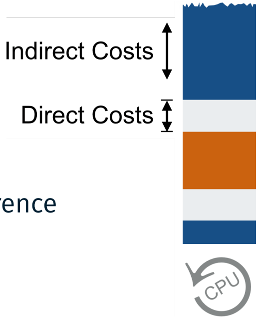


- cores are shared between heterogeneous workload
  - different applications and their threads
  - application, library and OS code
  - ⇝ interference, scheduling overhead
  - ⇝ decreased performance
- Is there a better way to operate many-core systems?

AAM

- Asynchronous Abstract Machines (AAMs) as a new system design approach for reduced noise
- address shortcomings of existing systems:
  1. heavy-weight threads and system calls
  2. missing OS-level support for teams
  3. static allocation of resources

Transitions Costs between Workloads



- direct costs
  - ⇝ time required for actual transition (e.g., mode switch or context switch)
- indirect costs
  - ⇝ executing other workload causes interference
    - – instruction/data caches
    - – Translation Lookaside Buffer (TLB)
    - – branch prediction units
  - ⇝ decreased instructions-per-cycle (IPC) performance

Indirect Costs of System Calls

⇝ significant impact on the user-space performance of the CPU for several thousand cycles [1]

[1] L. Soares, M. Stumm; "Flexible system call scheduling with exception-less system calls"

Kernel-level Scheduling

- requires expensive mode change
- threads have large memory footprint

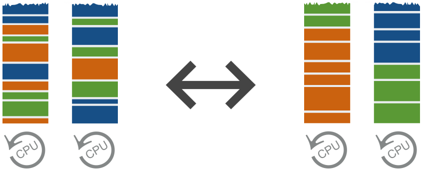
⇝ unsuited for micro-parallelism

User-level Scheduling

- reduced scheduling overhead
- prone to blocking anomaly (w/o native OS support)
  1. user-level task issues a system call
  2. OS blocks the execution context (thread) in the kernel
  3. thread becomes unavailable for user-level scheduler

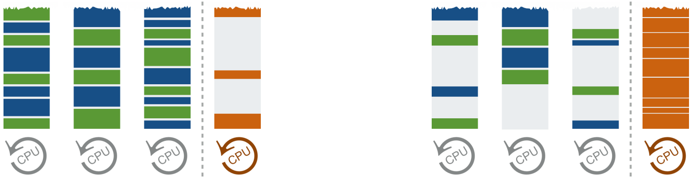
⇝ unsuited for system-intensive workload

- thread pools: common technique to parallelize tasks and reduce scheduling overhead
- shortcomings
  - OS has no notion of thread pools and work queues
    - is unaware that these threads form a team and execute similar tasks
    - lacks information: amount of tasks (load)
    - ⇝ subpar scheduling
  - optimal number of threads ?
    - ⇝ available resources, future workload, overall system load

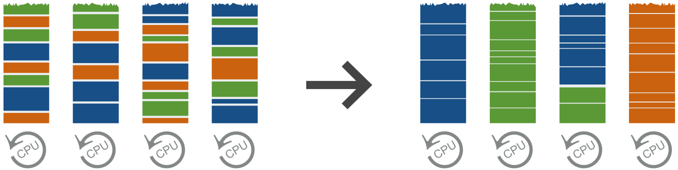


[1] D. R. Cheriton; "The V kernel: A Software Base for Distributed Systems"

- static allocation of resources
  - offloading system functionality to dedicated cores (e.g., to reduce noise)
  - allocation of a fixed number of threads (e.g., in a thread pool)
- changing workload causes imbalance
  - poor resource utilization
  - performance bottlenecks



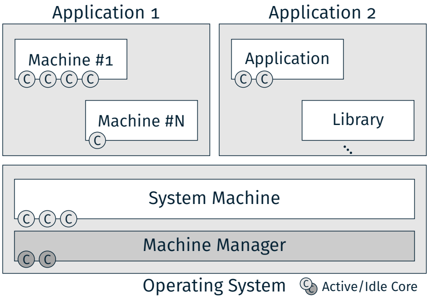
- operate cores more efficiently
  - **avoid transitions** between heterogeneous workloads
    - partition workload into groups of homogeneous tasks
    - dedicate cores to these groups
  - **speedup transitions** between homogeneous workloads
    - lightweight tasks
    - user-level scheduling
- address problems within user **and** kernel space



Concept

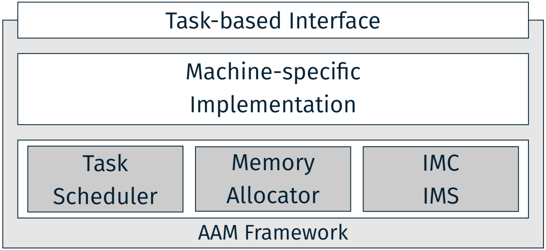
System Overview

- Asynchronous Abstract Machine (AAM)
  - dedicated to a specific group of tasks (shared code/data)
  - lightweight task scheduler
  - asynchronous task-based interface
- entire system is composed of AAMs (⇝ Applications, OS)
- Machine Manager: dynamic allocation of cores to AAMs



Components of an AAM

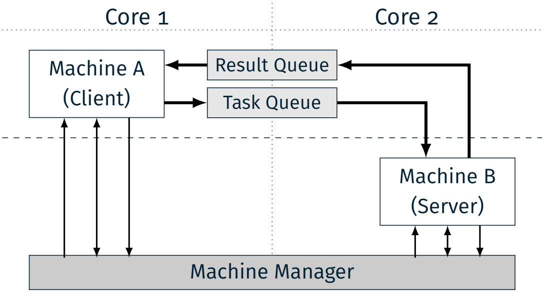
- AAMs may use their own task scheduler and allocator
- AAM Framework offers default implementations



IMC Inter-machine communication

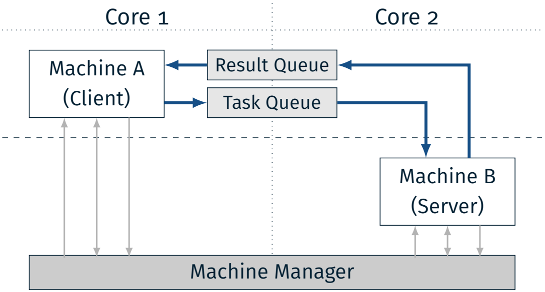
IMS Inter-machine signaling

Interaction of System Components



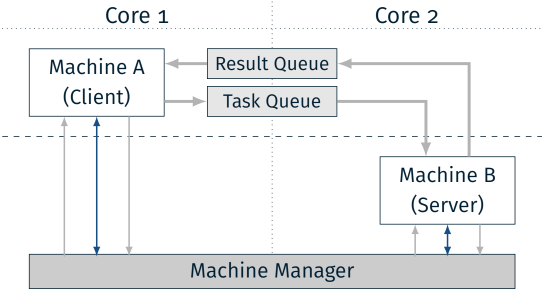
- Machine Manager
  - machine scheduling
  - inter-machine signaling
- Machine Interfaces
  - queues in shared memory
  - direct communication between machines

Inter-machine Communication (IMC)



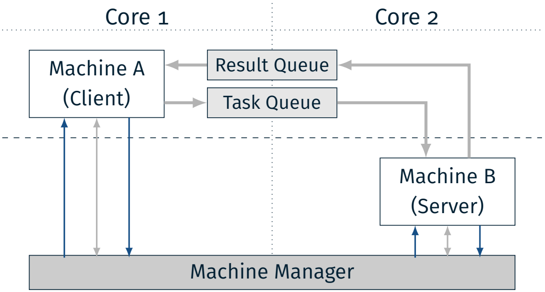
- AAMs offer predefined tasks to client machines
  - ⇝ scheduled asynchronously on server machines
- direct IMC does not involve the OS kernel (in the common case)

Inter-machine Signaling (IMS)



- Inter-machine signals (delivered by Machine Manager)
  - wake sleeping machines
  - register new interfaces
- involves traditional system calls
  - short and run-to-completion
  - ⇝ minimal indirect costs

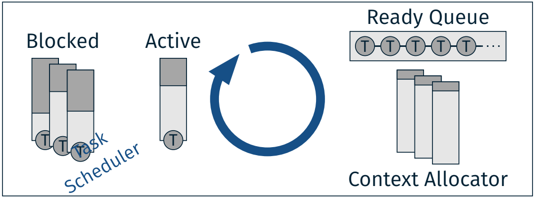
Machine Scheduling



- Machine scheduling allocates cores to AAMs
  - maximize utilization
  - minimize interference
- Machine Manager is aware of all machines
  - machine load
  - recent core utilization
  - prior core allocations

Scheduling Tasks within AAMs

- optimized for a huge number of short-lived tasks
  - task identifier, parameters, future
  - run-to-completion
  - lazy context allocation
  - ⇝ small memory footprint
- Machine-local scheduler
  - ⇝ scheduling does not involve OS kernel
  - ⇝ switching between tasks is inexpensive

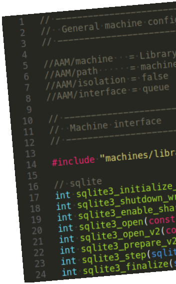


Implementation and Evaluation

Specifying AAMs at Design-time

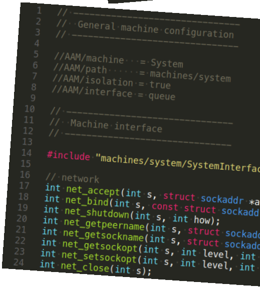
Considerations

- duration and cache behavior of operations
- shared data or functionality between operations
- distinct computation stages or system boundaries
- required privileges and isolation requirements



Specification and Reusability

- interface is defined in an IDL file
  - ⇝ C-compatible format
  - ⇝ automatic code generation
- self-contained with well-defined interface
  - ⇝ AAMs are reusable (like libraries)



Asynchronous Interface

⇝ returns immediately with a future; allows for latency hiding and batching

```
char buffer[MAX_LEN];
auto *rt = System::readAsync(fd, buffer, MAX_LEN);

// do other stuff ...

ssize_t result = rt->force();
```

Synchronous Interface

⇝ calling task waits for completion; another task is scheduled

```
char buffer[MAX_LEN];
ssize_t result = System::read(fd, buffer, MAX_LEN);
```

Event-based Interface

⇝ schedules a specified task on completion (work in progress)

Current State of the Prototype

Target Architectures

- native OS for x86-64
  - ⇝ benchmarking
- Linux 64-bit application
  - ⇝ development and debugging

Components

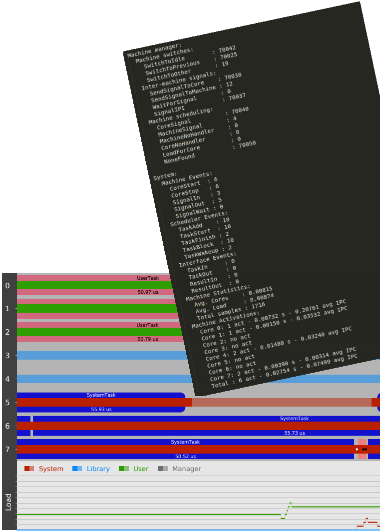
- AAM Framework
  - lightweight task scheduler
  - memory allocator
  - inter-machine communication
- Machine Manager
  - machine scheduler
  - inter-machine signaling

Reusable Machines

- library machines (user level)
  - SQLite
  - AES encryption
  - ZLIB/LZO compression
- system machines (kernel level)
  - TCP/IP stack
  - file system

Tools and Profiling Support

- iGen code generator
- sView scheduling analyzer
- CPU performance counters
- per-machine metrics (IPC, ...)



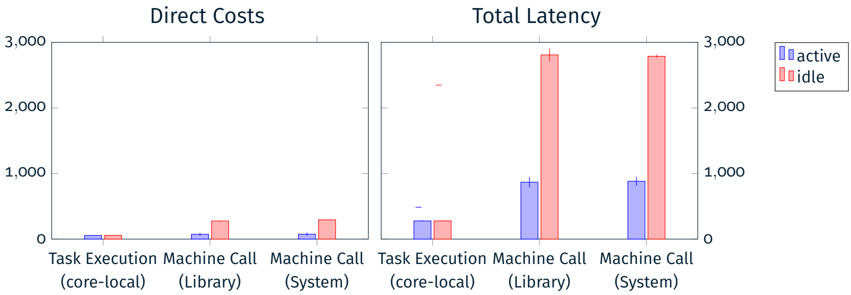
Costs of Typical System Operations

- local task execution
  1. create task and add it to the scheduler ⇝ direct costs
  2. block active task (waiting for task completion)
  3. execute no-op task
  4. continue original task ⇝ total latency
- Machine Call
  ⇝ task execution on different machine and core via IMC

Evaluation Setup

- Intel Xeon CPU E3-1275 v3 @ 3.50 GHz, 32 GiB RAM
- arithmetic mean and standard deviation from 10000 runs
- Linux (used for comparison): kernel version 4.4

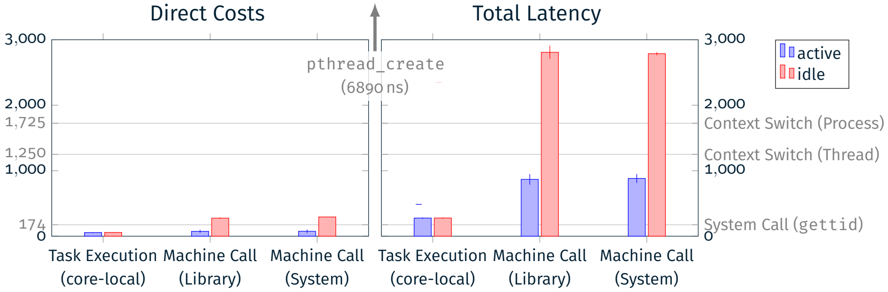
Evaluation Results



active AAMs actively monitor their interfaces

idle AAMs allowed to idle immediately (⇝ IMS)

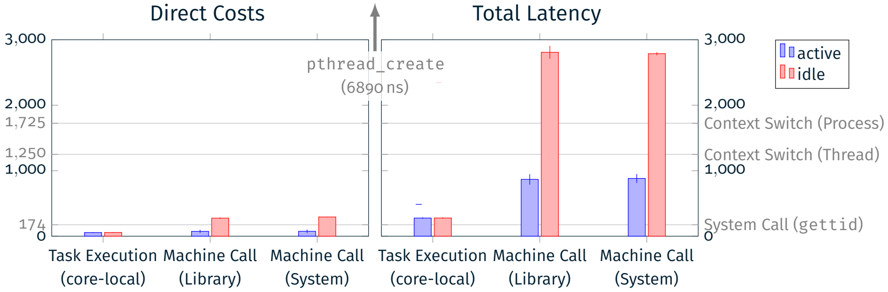
Evaluation Results



active AAMs actively monitor their interfaces

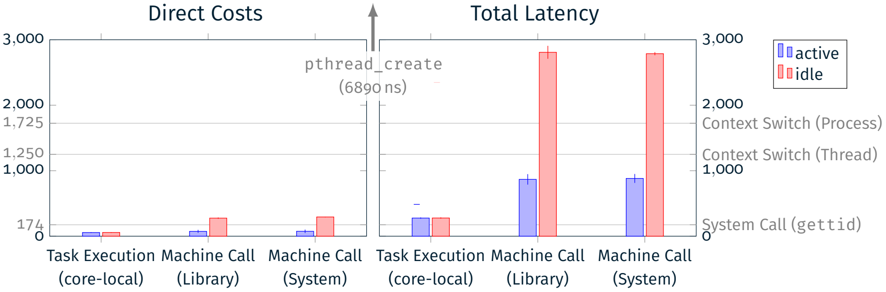
idle AAMs allowed to idle immediately (⇝ IMS)

costs of typical Linux operations in gray



Local Task Execution

- task creation is fast
- overhead for task scheduling is low



Machine Calls

- CPU becomes available to the caller after a short time
  - ⇝ latency hiding; schedule other task
- avoiding indirect costs comes with a latency overhead
  - ⇝ increased latency if IMS is required
  - ⇝ still low compared to most system calls or thread creation

Future Work and Conclusion

Future Work

- more micro and macro benchmarks
  - ⇝ e.g., HPC and server applications
- enhanced machine scheduling strategies
- isolation support
- hardware support for improved IMC performance
  - ⇝ Software-defined Hardware-managed Queues (SHARQ) [1] for communication across isolation domains

[1] S. Rheindt, S. Maier, F. Schmaus, T. Wild, W. Schröder-Preikschat, A. Herkersdorf; "SHARQ: Software-Defined Hardware-Managed Queues for Tile-Based Manycore Architectures"

Conclusion

- goals
  - avoid costly transitions between heterogeneous workload
  - speedup transitions between homogeneous workload
- AAM concept
  - partition system into machines with task schedulers
  - assign cores to machines exclusively during runtime
- addressed problems
  1. heavy-weight threads and system calls
     ⇝ machine-local task scheduling; task-based interface
  2. missing OS-level support for teams
     ⇝ Machine Manager is aware of all AAMs
  3. static allocation of resources
     ⇝ Machine Manager allocates cores dynamically