CAF - The C++ Actor Framework for Scalable and Resource-efficient Applications

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iNET

Previous Work

- Implemented native actor library `libcppa` actor library in C++
  - Target at both high-performance and embedded environments
  - Allow millions of lightweight actors
- Extended the actor model with publish/subscribe semantics
  - Original actor model only foresees 1:1 communication
  - Internet scale requires loose coupling
- Support heterogeneous hardware components
  - GPUs can outperform CPUs by orders of magnitude
  - Transparent integration of OpenCL allows flexible deployment

Rebranding & Modularization

Our approach to a growing userbase with diverse requirements:

- Move from a monolithic library to an open framework
- Split functionality into (optional) modules
- Enable customization via extensible framework structure
- Central project homepage[1] linking to all activities

[1] http://actor-framework.org

Agenda

1. Type-safe Message Passing
2. Scheduling Infrastructure
3. Runtime Inspection & Debugging
4. Conclusion & Outlook

Agenda

Problem of Dynamic Typing

The original model[2] defines actors in terms of

- (Untyped) message passing primitives
- Pattern matching

⇒ Extensive integration testing required

  - Coding errors occur at runtime
  - Non-local dependencies are hard to track manually

[2] Carl Hewitt, Peter Bishop, and Richard Steiger. A Universal Modular ACTOR Formalism for Artificial Intelligence.
In *Proceedings of the 3rd IJCAI*, pages 235–245, San Francisco, CA, USA, 1973. Morgan Kaufmann Publishers Inc.

Type-safe Message Passing

Lift type system of C++ and make it applicable to actor interfaces

- Compiler statically checks protocols between actors
- Protocol violation cannot occur at runtime
- Compiler verifies both incoming and outgoing messages:

```
using math =
  typed_actor<
    replies_to<int, int>::with<int>,
    replies_to<float>::with<float, float>>;
// ...
auto ms = typed_spawn(...);
sync_send(ms, 10, 20).then(
  [](float result) {
    // compiler error: result is int, not float
  }
);
```

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Scalability of Scheduling

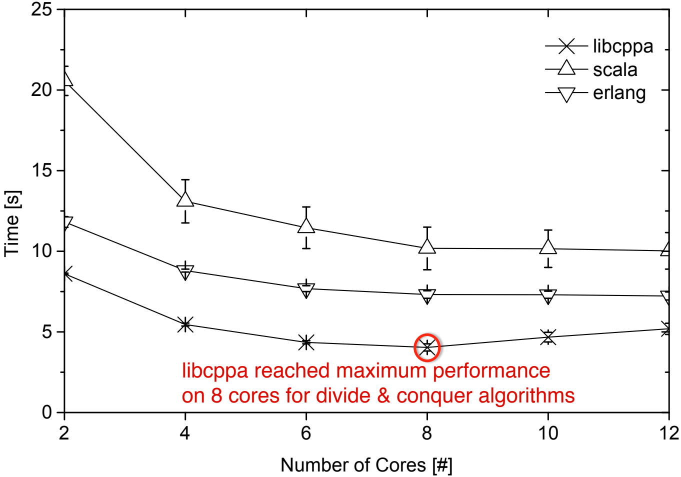
CAF aims at scaling to millions of actors on hundreds of processors

- Actors cannot be implemented (efficiently) as threads
- Running in userspace prohibits preemption
- Classical thread pool or centralized scheduler has limitations
    - Central job queue is a bottleneck per se
    - Short-lived tasks cause significant runtime overhead
    - *Could* schedule actors for real-time with a priori knowledge [3]

[3] M.L. Dertouzos and AK. Mok. Multiprocessor Online Scheduling of Hard-Real-Time Tasks. *Software Engineering, IEEE Transactions on*, 15(12):1497–1506, Dec 1989

Centralized Scheduling Issue

Divide & conquer: 2^{20} actors with `libcppa` (central scheduling, 2013)



Scheduling Approaches

- Active dispatching
  - Central task management
  - One (or more) threads manage others
  - High communication overhead
- Shared work queues
  - Reactive task management
  - Workers access one (or more) shared queues
  - Frequent access to shared data is a likely performance bottleneck
- Individual work queues
  - Decentralized, reactive task management
  - Workers communicate only when idle
  - Minimizes synchronizations between threads

Work Stealing

Decentralized scheduling using Work Stealing[4]

- One job queue and worker per core
- Worker tries *stealing* work items from others when idle
- Stealing is a rare event for most work loads[5]
- *But:* A priori knowledge cannot be exploited (no global view)

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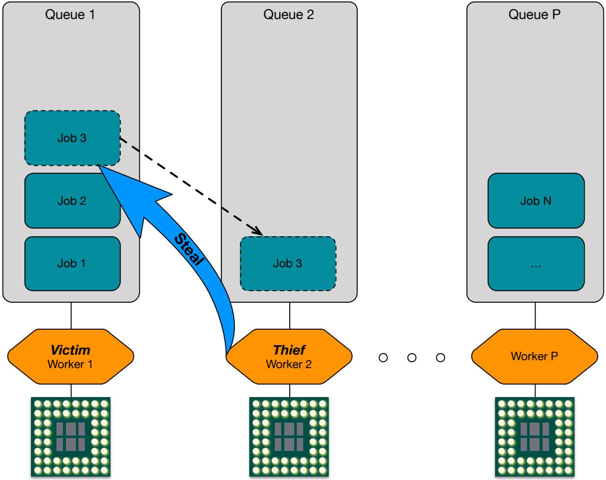
[4] Robert D. Blumofe and Charles E. Leiserson. Scheduling Multithreaded Computations by Work Stealing. *J. ACM*, 46(5):720–748, September 1999.

[5] Vivek Kumar, Daniel Frampton, Stephen M. Blackburn, David Grove, and Olivier Tardieu. Work-stealing Without the Baggage.
In *Proceedings of the ACM International Conference on Object Oriented Programming Systems Languages and Applications*, OOPSLA '12, pages 297–314, New York, NY, USA, 2012. ACM.

Work Stealing



Configurable Scheduling in CAF

Framework has no a priori knowledge → Work Stealing as default

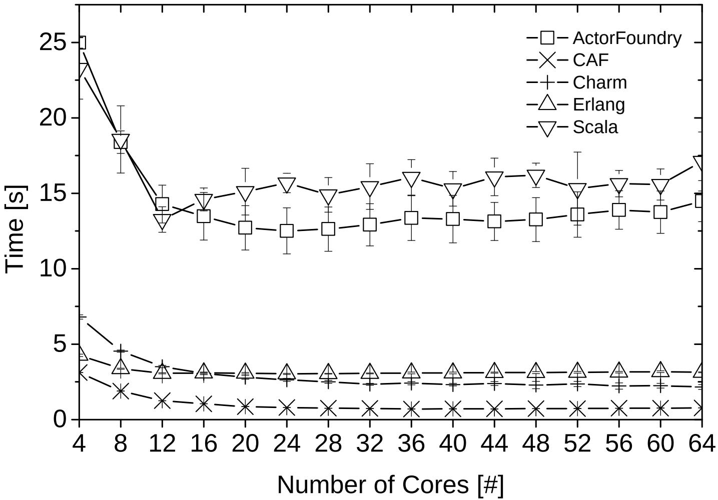
- Using Work Stealing, CAF scales up to at least 64 cores
- Developers can deploy custom scheduler using

```
template <class Policy = work_stealing>
void set_scheduler(size_t num_workers = ...,
                   size_t max_msgs = indefinite);
```

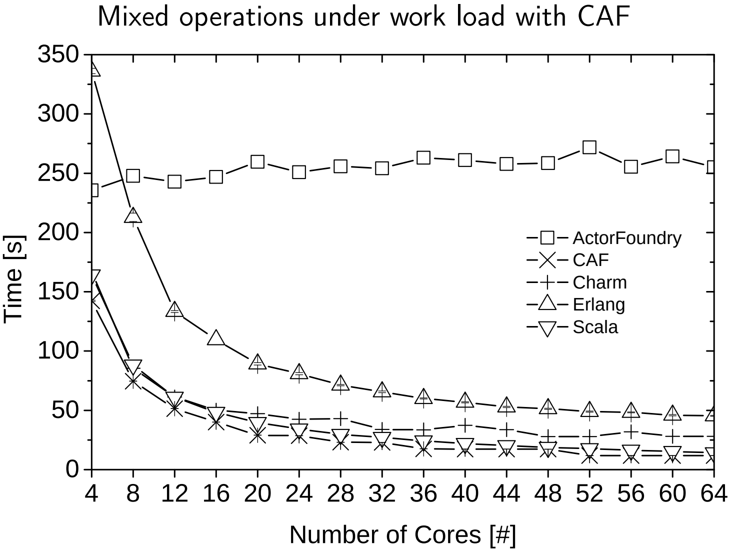
- `max_msgs` restricts # of messages actors can consume at once
  - Low value increases fairness and avoids bursts
  - High value minimizes queue access, usually maximizing throughput
- `Policy` can be implemented to exploit a priori knowledge, if possible

Scheduling Infrastructure

Divide & conquer: 2^{20} actors with CAF



Scheduling Infrastructure



Agenda

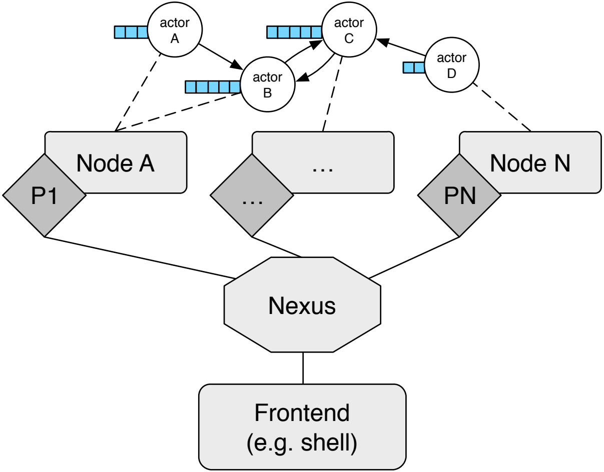
Runtime Inspection & Debugging

- Debugging of distributed systems is inherently complex
  - Non-trivial program flow
  - No global clock
  - Diverging states
- Recording messages crucial for on-line or post-mortem debugging
- Erroneous behavior can be reproduced using message replaying [6]
- Visualization tools can help understanding complex errors [7]

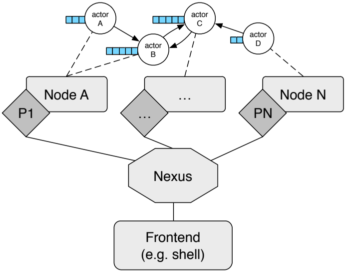
[6] Dennis Michael Geels, Gautam Altekar, Scott Shenker, and Ion Stoica. Replay debugging for distributed applications.
In *Proc. of USENIX'06 Ann. Tech. Conf.*, pages 289–300. USENIX Assoc., 2006.

[7] Terry Stanley, Tyler Close, and Mark S Miller. Causeway: A message-oriented distributed debugger.
Technical Report HPL-2009-78, HP Laboratories, 2009.

Runtime Inspection & Debugging



Runtime Inspection & Debugging



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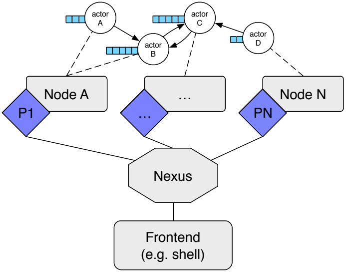
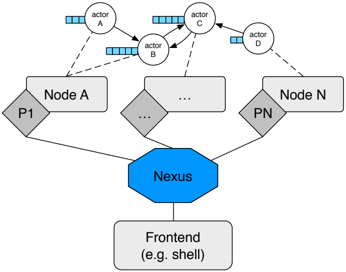


Probes

- Intercept & forward three kinds of messages to the Nexus:
  - **Activity events**: incoming & outgoing messages
  - **Error events**: network & system failures
  - **Runtime statistics**: periodic collection of CPU load, etc.

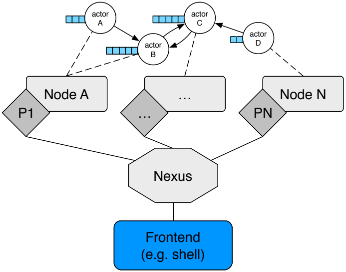
Runtime Inspection & Debugging



The Nexus

- Provides global view of the distributed system
- Receives & collects events from Probes
- Statefully configures verbosity of Probes

Runtime Inspection & Debugging



Frontend application categories

- **Observing agents**: monitoring & threshold-based alerts
- **Supervising agents**: active manipulation of running app.
- **Monitoring & visualization**: access to aggregate state
  - ⇒ For instance, an *interactive inspection shell*

Interactive Inspection Shell

```
Terminal — cash — 78×16
$ list-nodes
hostname123:1231
Sokrates:42
Platon:123
$ change-node Sokrates
$ statistics
           Node-ID:  afafafafafafafafafafafafafafafafafafafaf:42
          Hostname:  Sokrates
  Operating system:  Mac OS X
    CPU statistics:   #   Core No    MHz/Core
                      0         2        2300
         Processes:   5
            Actors:   3
CPU: [                                                  ] 0%
RAM: [#########################                         ] 512/1024
$
```

- Allows users to inspect distributed system
- In global mode:
  - Global view to the system
  - Access to individual participating nodes
- In node mode:
  - Access to statistics such as RAM usage, CPU load, etc.
  - Direct interaction with actors on that node

Agenda

Conclusion

- CAF is a robust, scalable platform for native actor programming
- Strong emphasis on low mem. footprint and performance
- Type-safe messaging interfaces
- Open scheduling infrastructure with efficient default
- First step towards debugging distributed actors

Outlook

- Scale down to IoT devices (port CAF to RIOT-OS[8])
- Load balancing for massively parallel, distributed systems
- Monitoring and debugging tools based on current platform
- Robust security layer for the IoT: subsuming strong authentication of actors in combination with opportunistic encryption

[8] http://riot-os.org

Thank you for your attention!

Homepage: http://actor-framework.org

Sources: https://github.com/actor-framework

iNET Working Group: http://inet.cpt.haw-hamburg.de

References

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