libcppa
Type-safe Messaging Systems in C++

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May 2014 @C++Now2014

Hochschule für Angewandte Wissenschaften Hamburg
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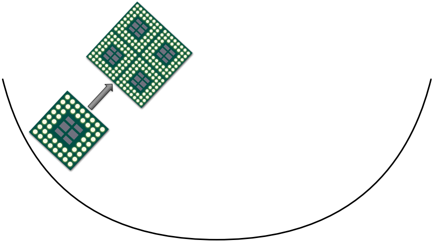
Agenda

Challenges of Scalable Software

Developers face not one, but multiple trends:

- More cores on both desktop & mobile plattforms



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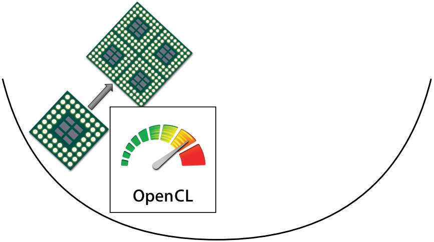

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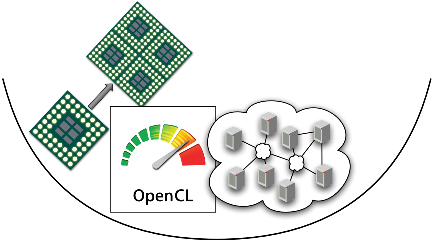
- Cloud computing: “Infrastructure as a service”
- Internet-wide deployment



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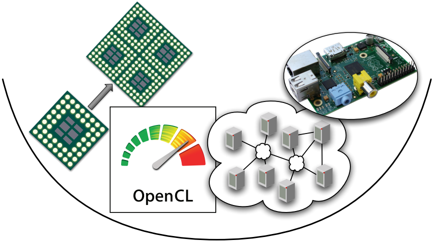
- Embedded HW & “The Internet of Things”



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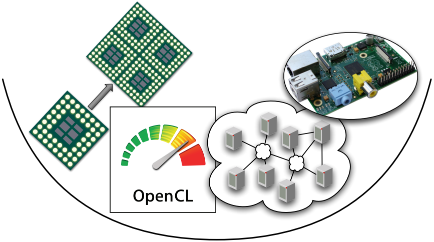
⇒ Heterogeneous platforms, concurrency & distribution



Raising the Level of Abstraction

Threads, Locks and Futures as found in the STL are **not** a sufficient abstraction. We should be enabled to ...

- Easily split application logic into as many tasks as needed
- Avoid race conditions by design (no locks!)
- Compose large systems out of small components *easily*
- Keep interfaces between software components stable:
    - Whether or not they run on the same host
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  ⇒ Flexible composition

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  - ⇒ Flexible composition

All of these criteria are met by the actor model.

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1. Introduction
    - Challenges of Scalable Software
    - What the Standard Provides
2. The Actor Model & `libcppa`
    - Benefits
    - Actors in C++11
    - API & Examples
3. Actors vs Threads
4. Performance Evaluation
    - Overhead of Actor Creation
    - Performance of N:1 Communication
    - Performance in a Mixed Scenario
    - Scaling Behavior of Message Passing
5. Conclusion

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- High-level, explicit communication between SW components
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  - Divide workload by spawning actors
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    - Divide workload by spawning actors
    - Network-transparent messaging
- Provides strong failure semantics
    - Hierarchical error management
    - Re-deployment at runtime

Actors and Native Programming

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  - Need to broaden range of applications
  - Deploy actors in performance-critical systems
- Actor systems need to include heterogeneous hardware
  - Integration of specialized HW components (GPGPU)
- Actor systems not available for embedded systems
  - Why not model the “Internet of Things” as network of actors?
  - HW platform should not dictate programming model
  - Portability & code re-use for developing IoT applications

Actors in C++11

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- Transparent integration of OpenCL-based actors
- Uses internal DSL for pattern matching of messages

`libcppa` Core Architecture

Type System

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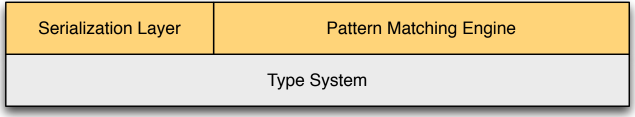

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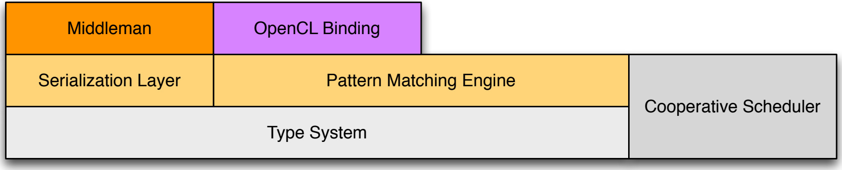

Middleman

OpenCL Binding

Serialization Layer

Pattern Matching Engine

Cooperative Scheduler

Type System

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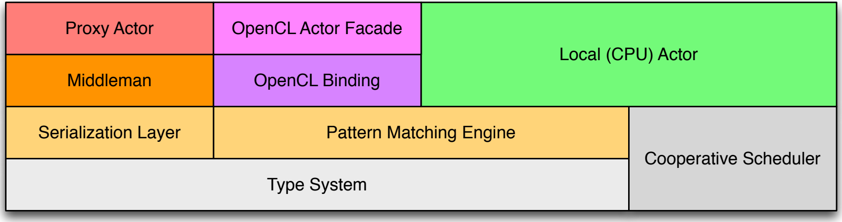

Proxy Actor

OpenCL Actor Facade

Local (CPU) Actor

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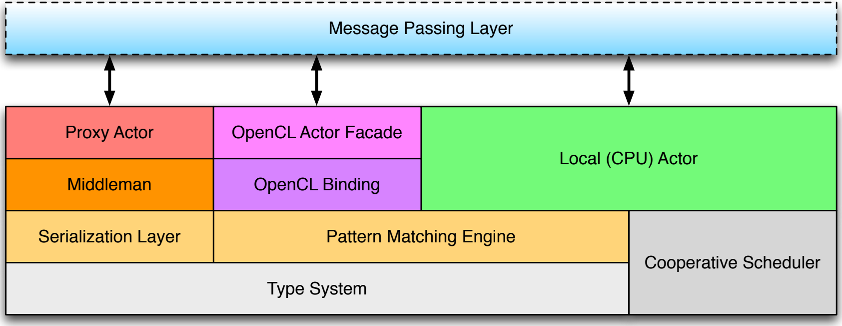

Message Passing Layer

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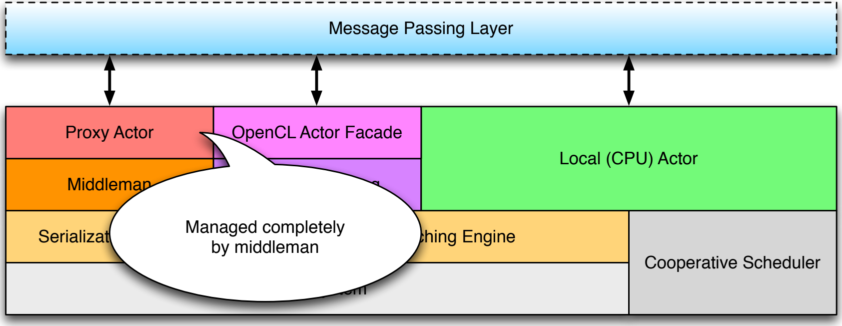

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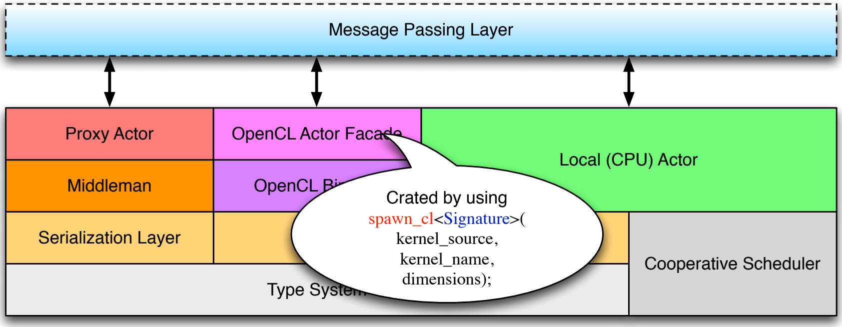
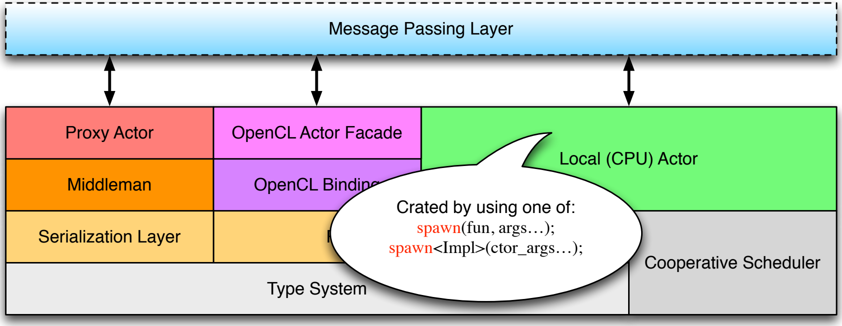


Crated by using
spawn_cl<Signature>(
kernel_source,
kernel_name,
dimensions);

`libcppa` Core Architecture



Message Passing Layer

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Crated by using one of:

`spawn(fun, args...);`

`spawn<Impl>(ctor_args...);`

API – Creating Actors

```
// args: constructor arguments for Impl
template<class Impl,
         spawn_options Os = no_spawn_options,
         typename... Ts>
actor spawn(Ts&&... args);

// args: functor followed by its arguments
template<spawn_options Os = no_spawn_options,
         typename... Ts>
actor spawn(Ts&&... args);
```

- Create actors from either functors or classes
- Spawn options can be used for monitoring, detaching, etc.
- Creates event-based actors per default

API – Event-based Actor Class

```
class event_based_actor : ... {

  template<typename... Ts>
  void send(actor whom, Ts&&... what);

  template<typename... Ts>
  response_handle sync_send(actor whom, Ts&&... what);

  void become(behavior bhvr);

  void quit(uint32_t reason);

  // ...

};
```

- Base for class-based actors
- Type of implicit `self` pointer for functor-based actors

API – Remote Communication

```
// makes actor accessible via network
void publish(actor whom, uint16_t port);

// get handle to remotely running actor
actor remote_actor(std::string host, uint16_t port);
```

- Message passing is network transparent
- Both local and remote actors use handles of type `actor`
- Network primitives not exposed to programmer

Example

```
behavior math_server() {
  return {
    [](int a, int b) {
      return a + b;
    }
  };
}
void math_client(event_based_actor* self, actor ms) {
  self->sync_send(ms, 40, 2).then(
    [=](int result) {
      cout << "40 + 2 = " << result << endl;
      }
  );
}
// spawn(math_client, spawn(math_server));
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// spawn(math_client, spawn(math_server));
```

return message handler for incoming messages (used until replaced or actor is done)

Example

```
behavior math_server() {
  return
    [](in
      ret
    }
  };
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send a message and then
wait for response
(using a "one-shot handler")

Example

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  );
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// spawn(math_client, spawn(math_server));
```

this actor "loops" forever
(or until it is forced to quit)

Example

this actor sends one message and receives one messages

```
behavior math_server() {
  r



  };
}
void math_client(event_based_actor* self, actor ms) {
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}
// spawn(math_client, spawn(math_server));
```

spawn server & client

API – Type Safety

- All functions are available as typed version
- Strongly typed actors use handles of type `typed_actor<...>`
- Interface is defined using `replies_to<...>::with<...>` notation
- Messaging to/from typed actors fully checked at compile time

API – Typed Actor Handles

Typed actor handles can be assigned to subtypes (even remote!):

```
using atype1 = typed_actor<replies_to<int>::with<int>,
                           replies_to<float>::with<float>>;
using atype2 = typed_actor<replies_to<int>::with<int>>;

atype1 a1 = spawn_typed(...);
atype2 a2 = a1; // assign to subtype
```

API – Typed Example

```
using math_t = typed_actor<replies_to<int,int>::with<int>>;
math_t::behavior_type math_server() {
  return {
    [](int a, int b) {
      return a + b;
    }
  };
}
void math_client(event_based_actor* self, math_t ms) {
  self->sync_send(ms, 40, 2).then(
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```

typedef with interface definition for convenience

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types of message handlers
must match interface definition

API – Typed Example

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}
// spawn(math_client, spawn_typed(math_server));
```

messages to ms now type-checked

API – Monitoring Example

```
behavior worker(); // sometimes fails

behavior master(event_based_actor* self) {
  auto w = self->spawn<monitored>(worker);
  return {
    [=](int a, int b) {
      self->send(w, a, b);
    },
    [=](const down_msg& msg) {
      if (msg.source == w) {
        // start a new worker
        self->become(master(self));
      }
    }
  };
}
```

Agenda

Actors vs Threads

Matrix multiplication as scaling behavior showcase:

- Large number of independent tasks
- Can make use of C++11's `async`
- Simple to port algorithm to GPU (because: why not?)

Multiply Matrices – Matrix Class

```
static constexpr size_t matrix_size = /*...*/;

// always rows == columns == matrix_size
class matrix {
 public:
  float& operator()(size_t row, size_t column);
  const vector<float>& data() const;
  // ...
 private:
  vector<float> m_data; // glorified vector
};
```

Multiply Matrices – Simple Loop

```
matrix simple_multiply(const matrix& lhs,
                       const matrix& rhs) {
  matrix result;
  for (size_t r = 0; r < matrix_size; ++r) {
    for (size_t c = 0; c < matrix_size; ++c) {
      result(r, c) = dot_product(lhs, rhs, r, c);
    }
  }
  return move(result);
}
```

Multiply Matrices – std::async

```
matrix async_multiply(const matrix& lhs,
                      const matrix& rhs) {
  matrix result;
  vector<future<void>> futures;
  futures.reserve(matrix_size * matrix_size);
  for (size_t r = 0; r < matrix_size; ++r) {
    for (size_t c = 0; c < matrix_size; ++c) {
      futures.push_back(async(launch::async, [&,r,c] {
        result(r, c) = dot_product(lhs, rhs, r, c);
      }));
    }
  }
  for (auto& f : futures) f.wait();
  return move(result);
}
```

Multiply Matrices – `libcppa` Actors

```
matrix actor_multiply(const matrix& lhs,
                      const matrix& rhs) {
  matrix result;
  for (size_t r = 0; r < matrix_size; ++r) {
    for (size_t c = 0; c < matrix_size; ++c) {
      spawn([&,r,c] {
        result(r, c) = dot_product(lhs, rhs, r, c);
      });
    }
  }
  await_all_actors_done();
  return move(result);
}
```

Multiply Matrices – OpenCL Actors

```
static constexpr const char* source = R"__(
  __kernel void multiply(__global float* lhs,
                         __global float* rhs,
                         __global float* result) {
    size_t size = get_global_size(0);
    size_t r = get_global_id(0);
    size_t c = get_global_id(1);
    float dot_product = 0;
    for (size_t k = 0; k < size; ++k)
      dot_product += lhs[k+c*size] * rhs[r+k*size];
    result[r+c*size] = dot_product;
  }
)__";
```

Multiply Matrices – OpenCL Actors

```
matrix opencl_multiply(const matrix& lhs,
                       const matrix& rhs) {
  using fvec = vector<float>;
  using cfvec = const fvec&;
                      // function signature
  auto worker = spawn_cl<fvec (cfvec, cfvec)>(
                  // code, kernel name & dimensions
                  source, "multiply",
                  {matrix_size, matrix_size});
  scoped_actor self;
  self->send(worker, lhs.data(), rhs.data());
  matrix result;
  self->receive([&](fvec& res_vec) {
    result = move(res_vec);
  });
  return move(result);
}
```

Multiply Matrices – Runtimes

Setup: 12 cores, Linux, GCC 4.8, 1000x1000 matrices

```
time ./simple_multiply
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time ./opencl_multiply
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time ./async_multiply
terminate called after throwing an instance of ’std::system_error’
  what():  Resource temporarily unavailable
```

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… and one cannot start 1,000,000 threads

Multiply Matrices – Summary

- Threads do **not** scale up to large numbers, actors do
- Spawning actors is fast
  - A million actors in $\leq 1.1\,\mathrm{s}$
  - Approach ideal speedup despite spawning $>$ 80k actors per CPU
- Yes, porting algorithms to GPUs is indeed worthwhile
  - Speedup is ludicrous
  - Shouldn't surprise anybody

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   - Performance in a Mixed Scenario
   - Scaling Behavior of Message Passing
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Measurements

Benchmarks are based on the following implementations:

`libcppa`	C++ (GCC 4.8.1) with libcppa
`scala`	Scala 2.10 with the Akka library
`erlang`	Erlang 5.10.2

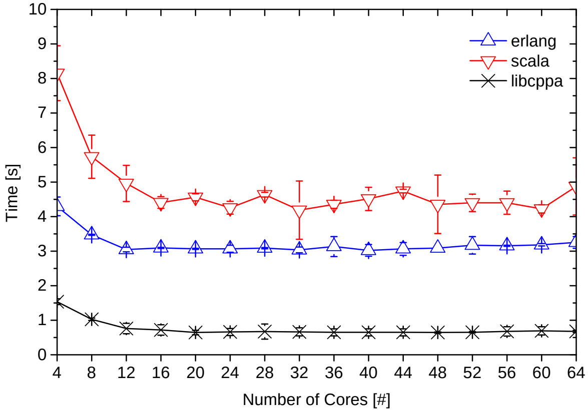
System setup:

- Four 16-core AMD Opteron 2299 MHz
- JVM configured with a maximum of 10 GB of RAM
- We vary the number of CPU cores from 4 to 64

Overhead of Actor Creation

- Fork/join workflow to compute 2^N
  - Each fork step spawns two new actors
  - Join step sums up messages from children
  - Each actor at the leaf sends 1 to parent
- Benchmark creates $\approx$ 1,000,000 actors ($N = 20$)

Overhead of Actor Creation

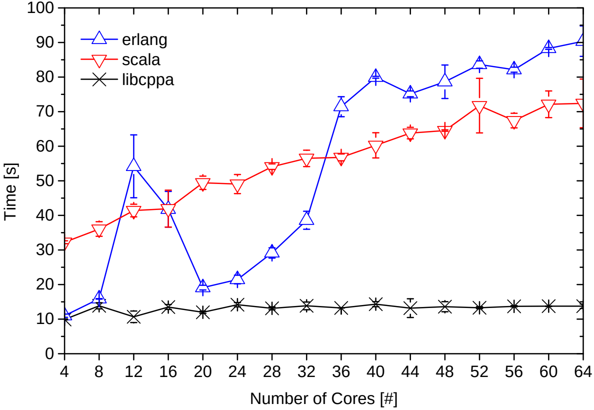


- All three implementations scale up to large actor systems
- `libcppa` performs best: 1M actors in $\leq 1\,\text{s}$ for 8 or more cores

Performance of 1:N Communication

- 100 senders transmitting 100k messages each to a single receiver
- Stresses performance of receive for central actors
- More HW concurrency adds more collisions on receiver mailbox

Performance of N:1 Communication

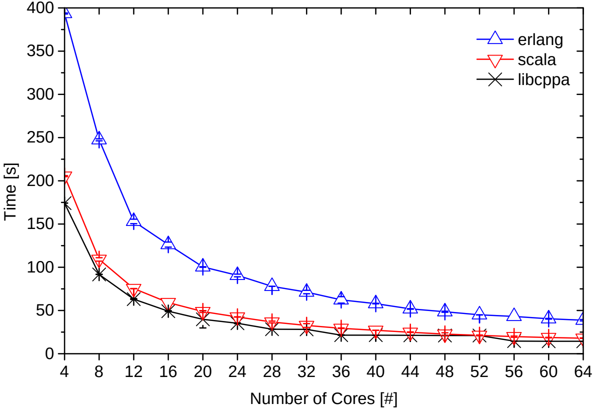


- Runtime increases significantly for Erlang and Scala
- `libcppa` remains almost constant

Performance in a Mixed Scenario

- Mixed operations under work load
- 100 rings of 50 actors each
- Token-forwarding on each ring until 1k iterations are reached
- 5 re-creations per ring
- One prime factorization per (re)-created ring to add work load
- Doubling the number of cores should (nearly) halve the runtime

Performance in a Mixed Scenario

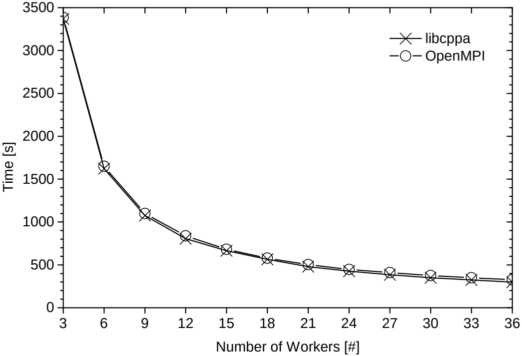


- Tail-recursive prime factorization in Scala as fast as in C++
- `libcppa` on 64 cores still ≈ 20 % faster

Scaling Behavior of Message Passing

- Calculate images of the Mandelbrot set in C++
- Distributed using (1) `libcppa` and (2) OpenMPI
    - Same source code for calculation
    - Only the message passing layers differ

Scaling Behavior of Message Passing



- Both implementations exhibit equal scaling behavior
- Doubling the number of worker nodes halves the runtime
- `libcppa` 20–30 s faster, despite higher level of abstraction

Agenda

Conclusion

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  - Small memory footprint & efficient program execution
- Native C++ actor system
  - Pattern Matching for messages as internal DSL
  - High level of abstraction without sacrificing performance
- Currently ported to RIOT-os[1] for embedded HW support

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[1] `http://www.riot-os.org/`

`libcppa` Facts Sheet

- Open source (GPLv2) `C++11` actor library
- Runs on GCC $\geq$ 4.7, Clang $\geq$ 3.2 (Linux + Mac)
- Will run on MSVC once it is C++11 complete (runs on MinGW)
- Hosted on GitHub
- Feedback & contributions always welcome!
- Hot topics in the iNET group:
  - Actors on ARM / embedded systems
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- Currently in (preliminary) submission process to Boost!

Thank you for your attention!

Developer blog: http://libcppa.org

Sources: https://github.com/Neverlord/libcppa

iNET working group: http://inet.cpt.haw-hamburg.de