RELEASE Scalable Erlang

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and RELEASE Team

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Outline

RELEASE Aim

To scale the radical actor (concurrency-oriented) paradigm to build reliable general-purpose software, such as server-based systems, on massively parallel machines (10^5 cores).

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- **Language aspects**, e.g. maintaining a fully connected network of nodes, explicit process placement
- **Tool support**

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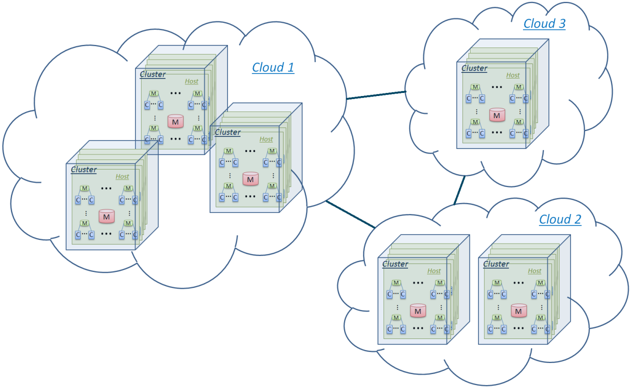
Typical Target Architecture - 10^5 cores

- Commodity hardware
- Non-uniform communication
  (Level0 – same host, Level1 – same cluster, etc)



Erlang Overview

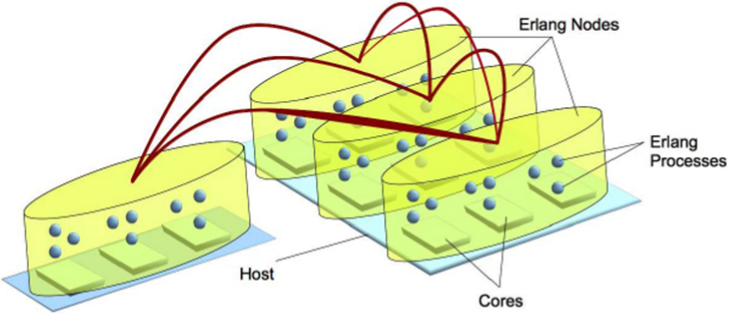
Erlang

- is a functional general purpose concurrent programming language developed in 1986 at Ericsson
- is dynamically typed
- was designed for distributed, fault-tolerant, massively concurrent, and soft-real time systems
- follows *let it crash* and *share nothing* philosophy

The language primitives are processes.
Erlang concurrency is handled by the language and not by the operating system [Arm10].

Distributed Erlang

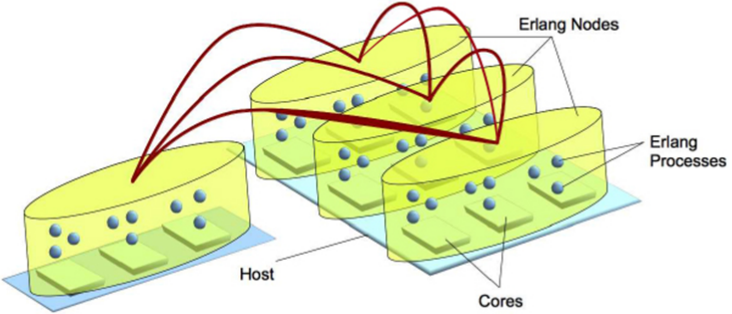
- Transitive connections



Distributed Erlang

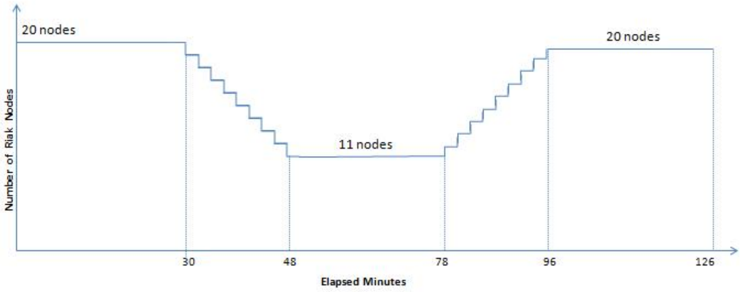
- Transitive connections
- Explicit Placement, i.e.

```
spawn(Node, Module, Function, Args) → pid()
```

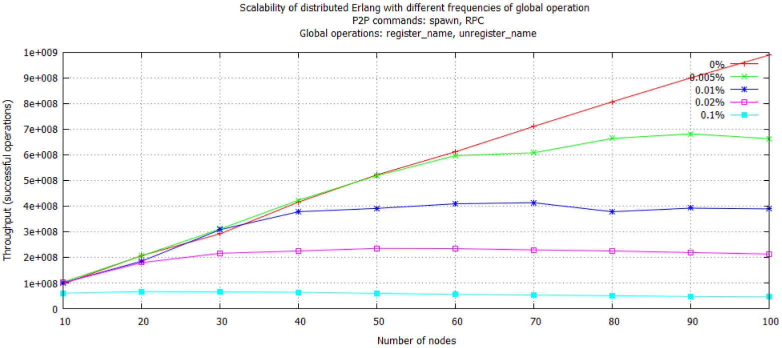


Distributed Erlang

- **Reliability:** multiple hardware and software redundancy means that if one Host or Node fails, other Nodes can continue to deliver service

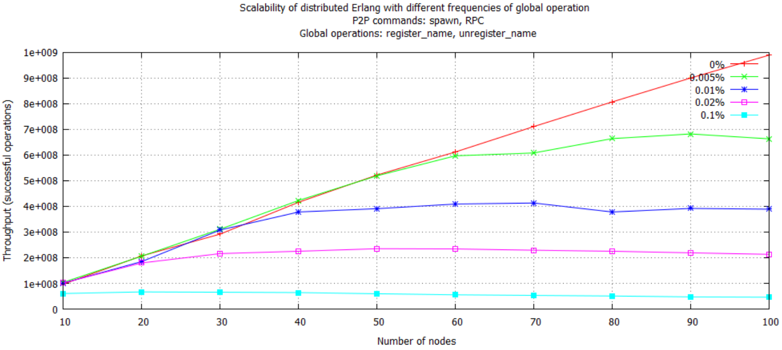


Distributed Erlang Scalability Limitations



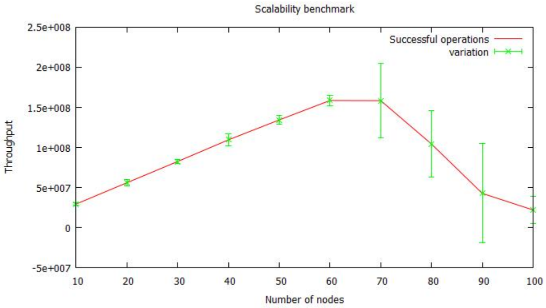
- Global operations, i.e. registering names using `global` module

Distributed Erlang Scalability Limitations



- Global operations, i.e. registering names using `global` module
- Other global operations, e.g. using `rpc:call` to call multiple nodes

Distributed Erlang Scalability Limitations



- Single process bottlenecks, e.g. overloading `rpc`'s `rex` process
- All-to-all connections

Design Approach & Principles

Need to scale

- Persistent data structures (Riak, Casandra)
- In-memory data structures (Uppsala University, Ericsson)
- Computation

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SD Erlang design principles

- Working at Erlang level as far as possible
- Preserving the Erlang philosophy and programming idioms
- Keeping Erlang reliability model unchanged as far as possible
- Minimal language changes
- Avoiding global sharing
- Introducing an abstract notion of communication architecture

Scaling Computation

SD Erlang is a small conservative extension of Distributed Erlang

- **Network Scalability**
  - All-to-all connections are not scalable onto 1000s of nodes
  - *Aim:* Reduce connectivity
- **Semi-explicit Placement**
  - Becomes not feasible for a programmer to be aware of all nodes
  - *Aim:* Automatic process placement in groups of nodes

Network Scalability

Types of nodes

- Free nodes (normal or hidden) belong to *no s_group*
- S_group nodes belong to *at least one s_group*

Nodes in an s_group have transitive connections only with nodes from the same s_groups, but non-transitive connections with other nodes

Network Scalability

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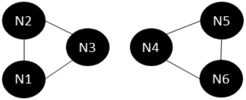
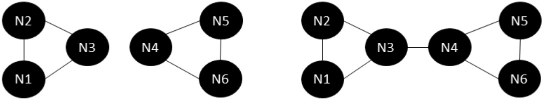
S_groups replace distributed Erlang global_groups:

- Similarities
  - groups have their own namespaces
  - transitive connections only between nodes from the same group
- Differences
  - a node can belong to an unlimited number of s_groups
  - information about s_groups and nodes is not globally shared

Free Node Connections vs. S_group Node Connections



Free Node Connections vs. S_group Node Connections



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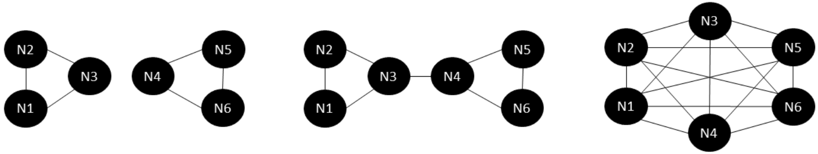

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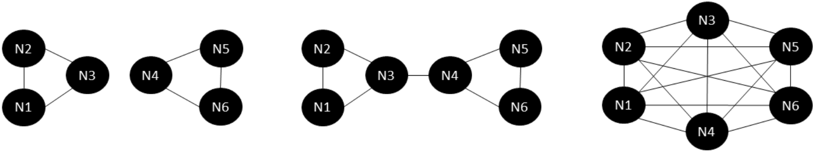

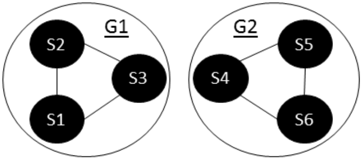

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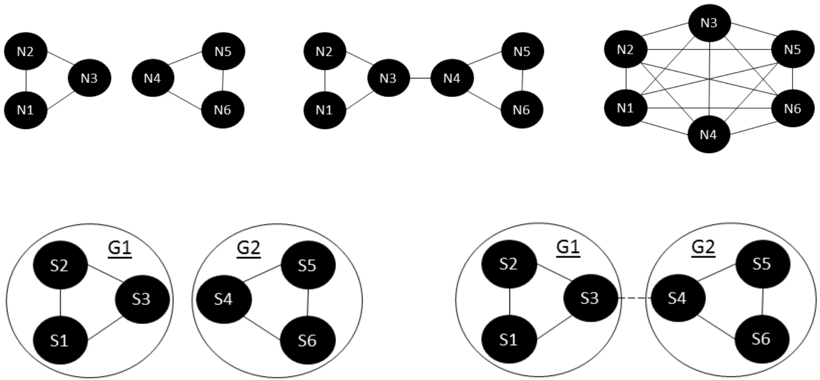
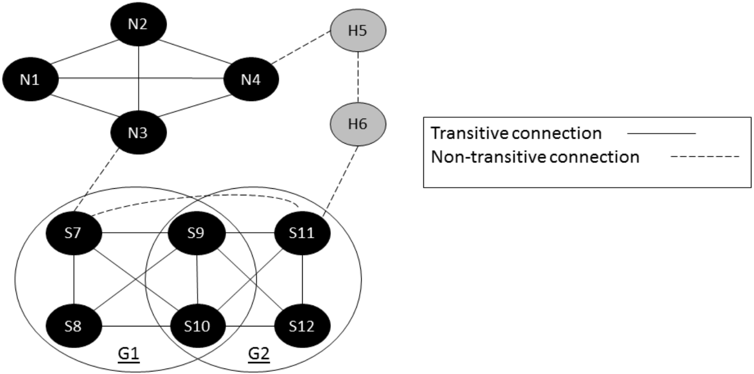


Connections between Different Types of Nodes



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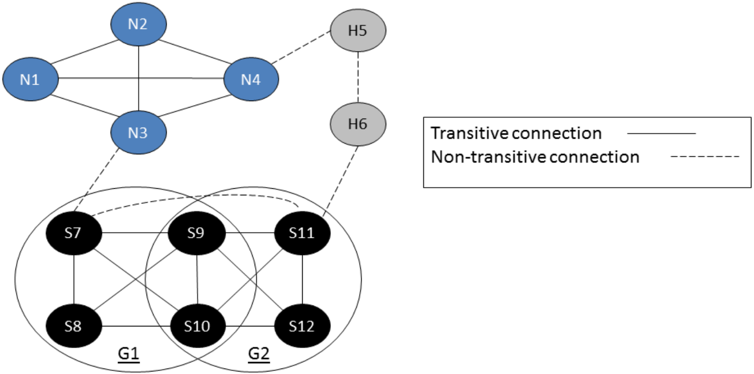

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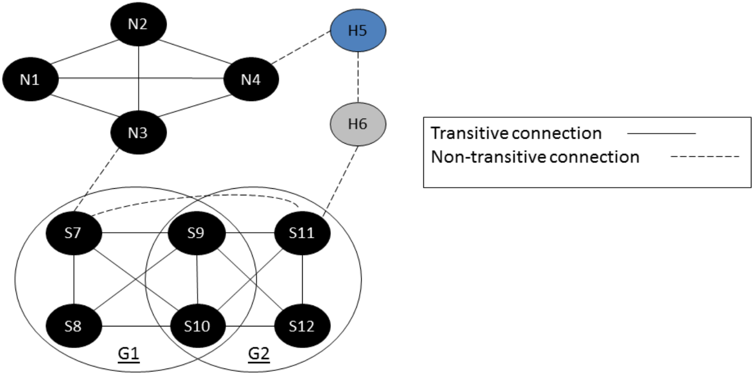

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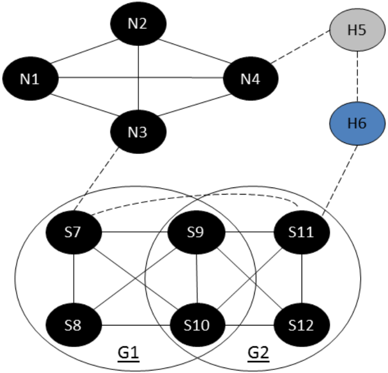
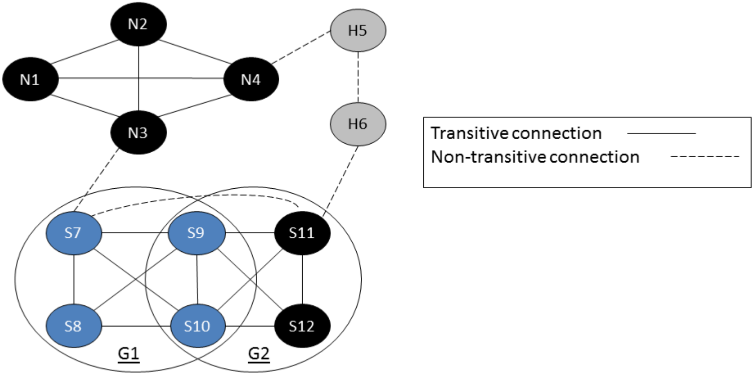


Transitive connection	————
Non-transitive connection	--------

Connections between Different Types of Nodes



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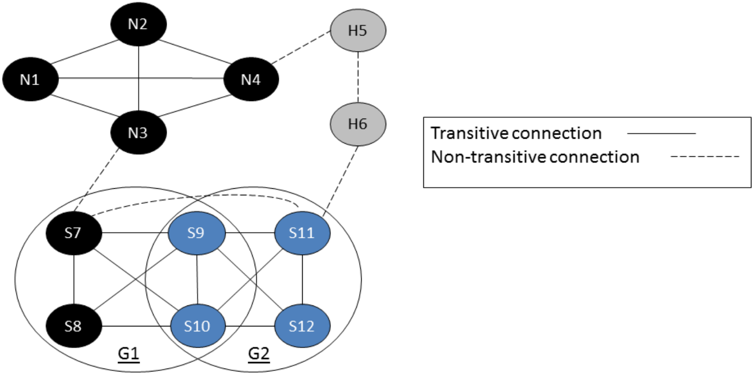


Why s_groups?

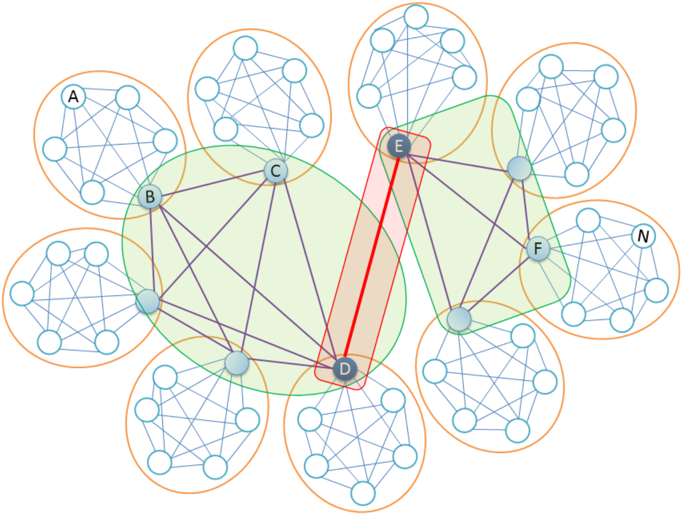
Requirements to the node grouping approach

- Preserve the distributed Erlang philosophy, i.e. any node can be directly connected to any other node
- Adding and removing nodes from groups should be dynamic
- Nodes should be able to belong to multiple groups
- The mechanism should be simple

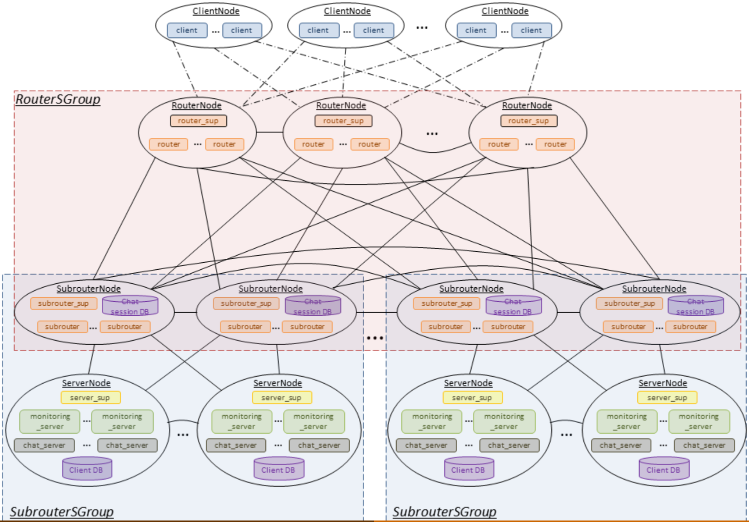
A list of considered approaches

- Grouping nodes according to their hash values
- A hierarchical approach
- *Overlapping s_groups*

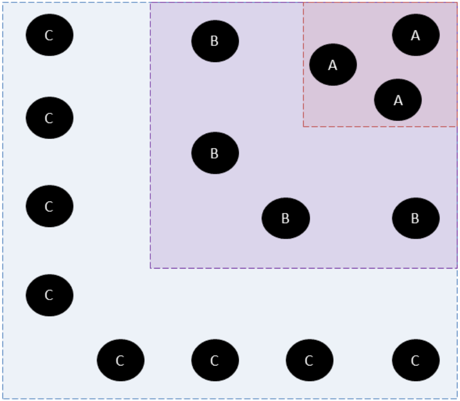
Hierarchical Grouping



Free Nodes and S_groups



Embedded Grouping



S_group Functions

S_groups can be started

- At launch using `-config` flag and a `.config` file
- Dynamically using `s_group:new_s_group/0,1` functions

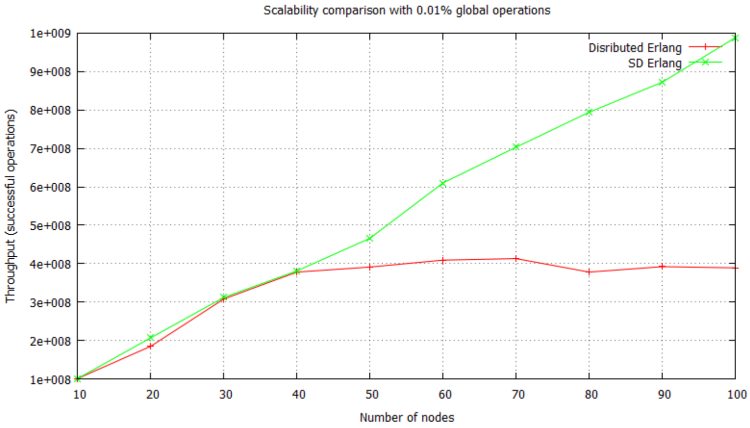
Main Functions

`new_s_group([Node])` → `{SGName, Nodes}` | `{error, Reason}`
`new_s_group(SGName, [Node])` → `{SGName, Nodes}` | `{error, Reason}`
`delete_s_group(SGName)` → `'ok'` | `{error, Reason}`
`add_nodes(SGName, Nodes)` → `{ok, SGName, Nodes}` | `{error, Reason}`
`remove_nodes(SGName, Nodes)` → `'ok'` | `{error, Reason}`

Additional Functions

S_group information: `s_groups/0, own_nodes/0,1, own_s_groups/0, info/0`
Name registration: `register_name/3, unregister_name/2, re_register_name/3`
Searching and listing names: `registered_names/1, whereis_name/2,3`
Sending a message to a process: `send/3,4`

SD Erlang Improves Scalability



Orbit Example

- Orbit is a symbolic computing kernel and a generalization of a transitive closure computation [LN01]
- To compute Orbit for a given space $[0..X]$ we apply on the initial vertex $x_0 \in [0..X]$ a list of generators $g1, g2, ..., gn$ that creates new numbers $(x_1 ... x_n) \in [0..X]$. The generator functions are applied on the new numbers until no new number is generated.

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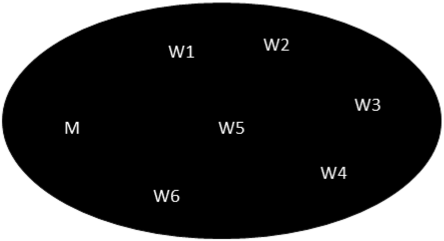
Why Orbit?

- Uses a Distributed Hash Table (DHT) similar to NoSQL DBMSs like Riak [Bas13], i.e. the hash of a value defined where the value should be stored
- Uses standard P2P techniques and credit/recovery distributed termination detection algorithm [MC98]
- Is only a few hundred lines and has a good performance and extensibility

Orbit in Non-distributed Erlang

Main components: `master.erl`, `worker.erl`, `table.erl`, `credit.erl`

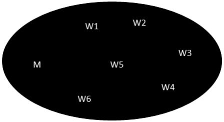
```
Pid = spawn_link(worker, init, [TabSize, TmOut, SpawnImgComp])
```



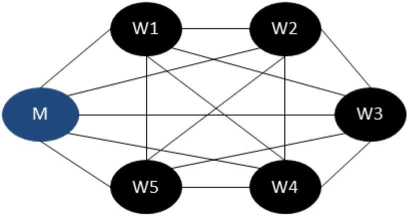
Orbit in Distributed Erlang

Main components: `master.erl`, `worker.erl`, `table.erl`, `credit.erl`

× Pid = spawn_link(worker, init, [TabSize, TmOut, SpawnImgComp])
✓ Pid = spawn_link(Node, worker, init, [TabSize, TmOut, SpawnImgComp])

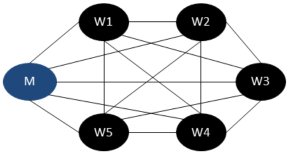


(a)

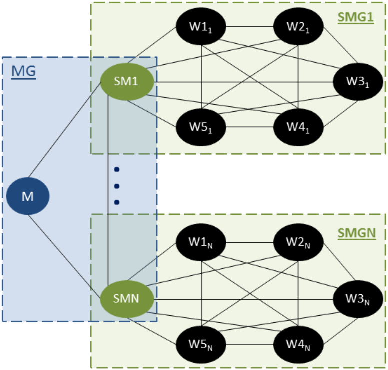


(b)

Distributed Erlang Orbit vs. SD Erlang Orbit



(c)



(d)

Distributed Erlang Orbit → SD Erlang Orbit

Distributed Erlang Orbit:

- `master.erl`, `worker.erl`, `table.erl`, `credit.erl`

SD Erlang Orbit:

- `master.erl`, `worker.erl`, `table.erl`, `credit.erl`
- + `submaster.erl`, `grouping.erl`

Kent team works on refactoring mechanisms

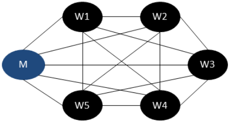
master.erl

Distributed Erlang Orbit

- Spawns worker processes

SD Erlang Orbit

- Spawns submaster and gateway processes



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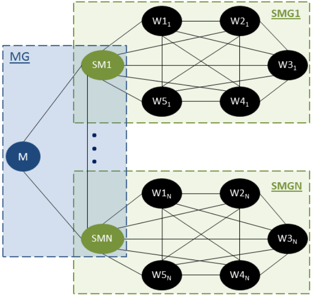


(f)

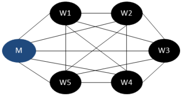
worker.erl

Distributed Erlang Orbit

- Sends a message with vertex X directly to the target process

SD Erlang Orbit

- Sends a message with vertex X directly to the target process only if the process is in the own s_group, otherwise sends it to a gateway process



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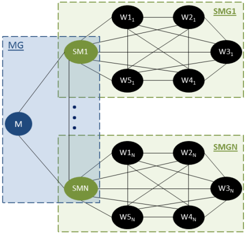


(b)

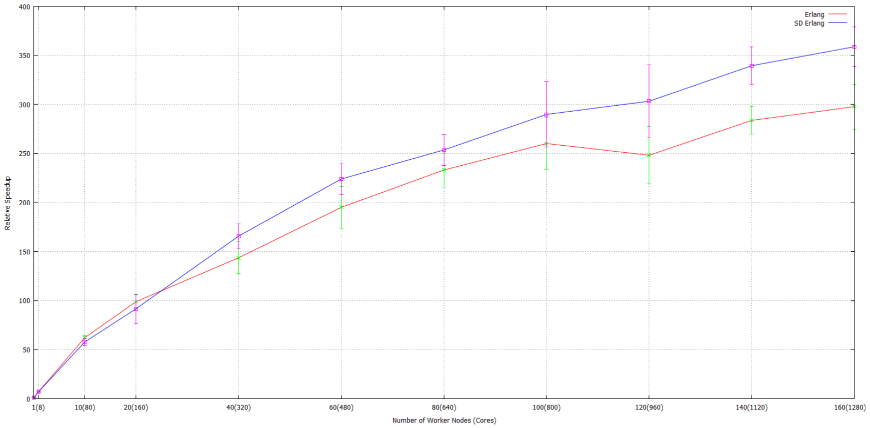
submaster.erl

- Initiates submaster and gateway processes
- Submaster processes start worker processes
- Submaster processes transfer credit from Worker processes to the Master Process
- Gateway processes receive {`Vertex, Credit`} pair and identify its corresponding s_group

SD Erlang grouping.erl

- Creation of s_groups on Submaster nodes
- Creation of the master s_group, i.e.

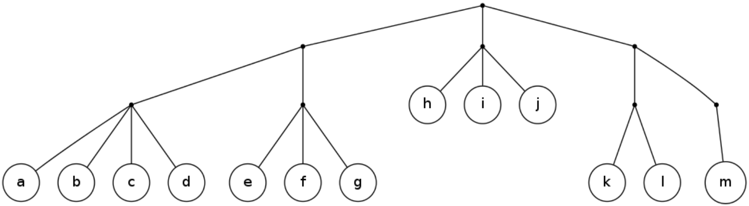
Speed Up of Distributed Erlang Orbit & SD Erlang Orbit



Semi-Explicit Placement

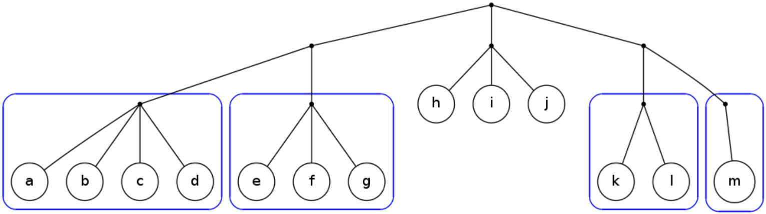
- In a distributed system, communication latencies between nodes may vary according to relative positions of the nodes in the system.
- Some nodes may be "nearby" in terms of communication time, while others may be further away (in a different cluster within a cloud, for example).
- We may wish some tasks to be close together because they're communicating with each other a lot, or we may wish to spawn it nearby to reduce communication overhead, or to spawn it on a distant node which is lightly loaded.

Example



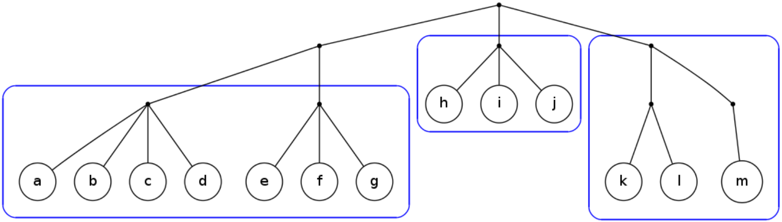
System structure

Example: system structure



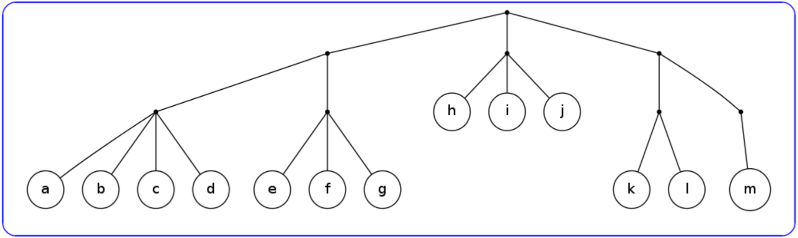
Racks

Example: system structure



Clusters

Example: system structure



Cloud

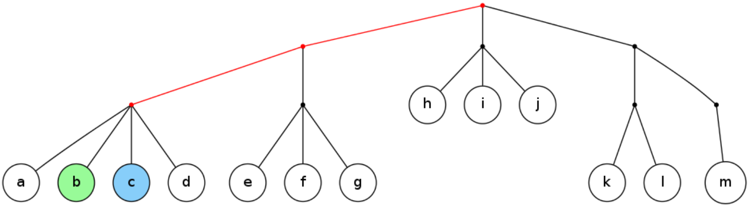
Measuring communication distance

We can define a *distance function* d on the set V of Erlang VMs in a distributed system by

$$d(x,y) = \begin{cases} 0 & \text{if } x = y \\ 2^{-\ell(x,y)} & \text{if } x \neq y. \end{cases}$$

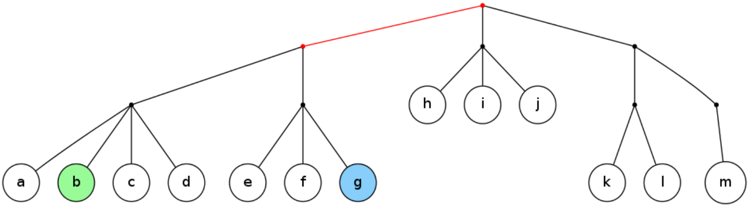
where $\ell(x,y)$ is the length of the longest path which is shared by the paths from the root to x and y.

Distances



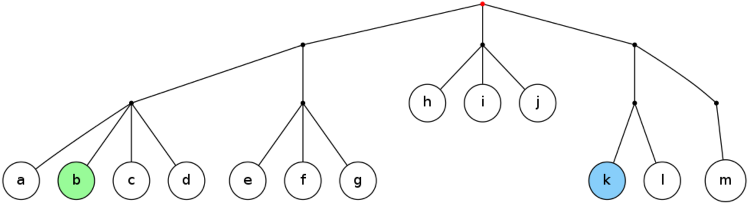
$$\ell(b, c) = 2$$
$$d(b, c) = 2^{-2} = 1/4$$

Distances



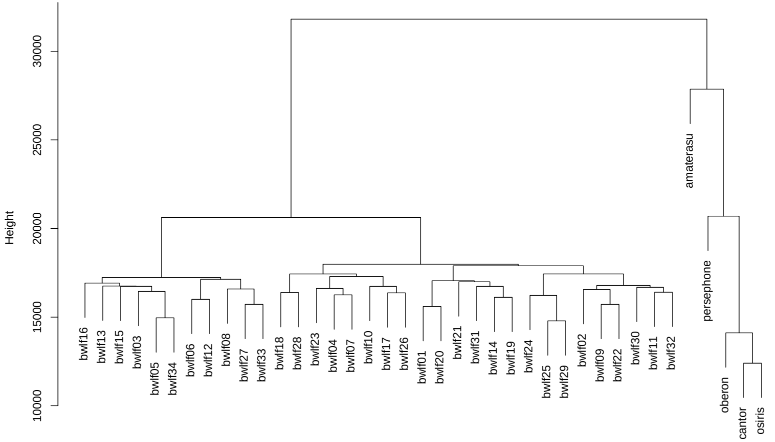
$$\ell(b, g) = 1$$
$$d(b, g) = 2^{-1} = 1/2$$

Distances



$$\ell(b, k) = 0$$
$$d(b, k) = 2^{-0} = 1$$

Dendrogram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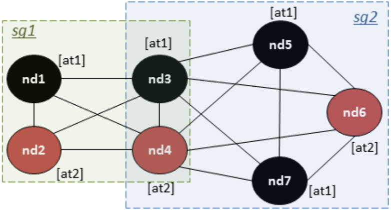
bwlf01
bwlf20
bwlf21
bwlf31
bwlf14
bwlf19
bwlf24
bwlf25
bwlf29
bwlf02
bwlf09
bwlf22
bwlf30
bwlf11
bwlf32
amaterasu
persephone
oberon
cantor
osiris

choose_nodes/1

- Every node may have a list of attributes



- choose_nodes/1 function returns a list of nodes that satisfy given restrictions

```
s_group:choose_nodes([Parameter]) -> [Node]
where
     Parameter = {s_group, SGroupName} | {attribute, AttributeName}
               | {nearer, 0.4} | {between, 0.5, 0.7}
     SGroupName = group_name()
     AttributeName = term()
```

S_group Operational Semantics

- Defined an abstract state of SD Erlang systems
- Presented the transitions of fifteen SD Erlang functions
  - Nine functions change their state after the transition: `register_name/3`, `re_register_name/3`, `unregister_name/2`, `whereis_name/3`, `send/2`, `new_s_group/2`, `delete_s_group/1`, `add_nodes/2`, `remove_nodes/2`
  - Six functions do not change the state after the transition: `send/3`, `whereas_name/2`, `registered_names/1`, `own_nodes/0`, `own_nodes/1`, `own_s_groups/0`

SD Erlang State

$$(grs, fgs, fhs, nds) \in \{state\} \equiv$$
$$\equiv \{(\{s\_group\}, \{free\_group\}, \{free\_hidden\_group\}, \{node\})\}$$

$$gr \in grs \equiv \{s\_group\} \equiv \{(s\_group\_name, \{node\_id\}, namespace)\}$$
$$fg \in fgs \equiv \{free\_group\} \equiv \{(\{node\_id\}, namespace)\}$$
$$fh \in fhs \equiv \{free\_hidden\_group\} \equiv \{(node\_id, namespace)\}$$
$$nd \in nds \equiv \{node\} \equiv \{(node\_id, node\_type, connections, gr\_names)\}$$

Property. Every node in an SD Erlang state is a member of one of the three classes of groups: *s_group*, *free_group*, or *free_hidden_group*. The three classes of groups partition the set of nodes.

Transitions

$$(\mathit{state}, \mathrm{command}, \mathit{ni}) \longrightarrow (\mathit{state}', \mathit{value})$$

Executing command on node *ni* in *state* returns *value* and transitions to *state*′.

register_name/3

SD Erlang function

s_group:register_name(SGroupName, Name, Pid) → yes | no

$$((grs, fgs, fhs, nds), \text{register\_name}(s, n, p), ni)$$
$$\longrightarrow ((\{(s, \{ni\} \oplus nis, \{(n, p)\} \oplus ns)\} \oplus grs', fgs, fhs, nds), \text{True})$$
$$\text{If } (n, \_) \notin ns \wedge (\_, p) \notin ns$$
$$\longrightarrow ((grs, fgs, fhs, nds), \text{False})$$
$$\text{Otherwise}$$

where

$$\{(s, \{ni\} \oplus nis, ns)\} \oplus grs' \equiv grs$$

Validation of Semantics and Implementation

- Validate the consistency between the formal semantics and the SD Erlang implementation
- Use Erlang QuickCheck tool developed by QuviQ
- Behaviour is specified by properties expressed in a logical form
- `eqc_statem` is a finite state machine in QuickCheck

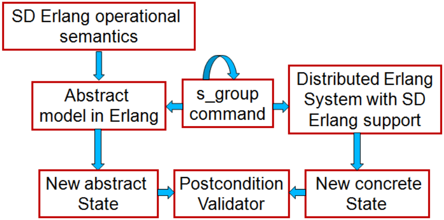


Figure: Testing SD Erlang Using QuickCheck `eqc_statem`

Precondition for new_s_group operation

$$precondition(\_State, \{call, ?MODULE, new\_s\_group, [\{\_SGroupName, NodeIds, \_CurNode\}, \_AllNodeIds]\}) \rightarrow$$

$$NodeIds /= [];$$

Postcondition for `new_s_group` operation

- **AbsRes** – abstract result; **AbsState** – abstract state
- **ActRes** – actual result; **ActState** – actual state

$$postcondition(State, \{call, ?MODULE, new\_s\_group, \{SGroupName, NodeIds, CurNode\}, \_AllNodeIds]\}, \{ActResult, ActState\}) \rightarrow$$

$$\{AbsRes, AbsState\} =$$
$$= new\_s\_group\_next\_state(State, SGroupName, NodeIds, CurNode),$$
$$(AbsResult == ActResult) \; and \; is\_the\_same(ActState, AbsState);$$

Future work

Semi-explicit Placement

- For reasons of portability and understandability it might not be desirable to expose too much information about distances to programmers. We may wish to implement a more abstract interface, using attributes along the lines of very close, close, medium, distant, very distant.
- Instead of describing the system structure in a configuration file, we will look into the possibility of discovering it at runtime.
- We also want to look into questions of robustness: it would be useful to have some means of dynamically adjusting our view of the system if new nodes join it, or if existing ones fail.

Future Plans

- Continue the work on SD Erlang Semantics
- Run **Sim-Diasca** simulation engine on massively parallel supercomputer **Blue Gene/Q** with approx. 65,000 cores
- SD Erlang to become standard Erlang
- Methodology, i.e. portability principles, scalability principles

Sources

- RELEASE Project http://www.release-project.eu/
- RELEASE github repos
  - SD Erlang https://github.com/release-project/otp/tree/dev
  - DEbench, Orbit https://github.com/release-project/benchmarks
  - Percept2 https://github.com/release-project/percept2
- BenchErl http://release.softlab.ntua.gr/bencherl/index.html
- Sim-Diasca simulation engine http://researchers.edf.com/software/sim-diasca-80704.html

Thank you!

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