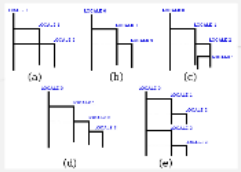
Transparently Resilient Task Parallelism for Chapel

Konstantina Panagiotopoulou, Hans-Wolfgang Loidl

Heriot-Watt University, Edinburgh, UK

Evaluation Results



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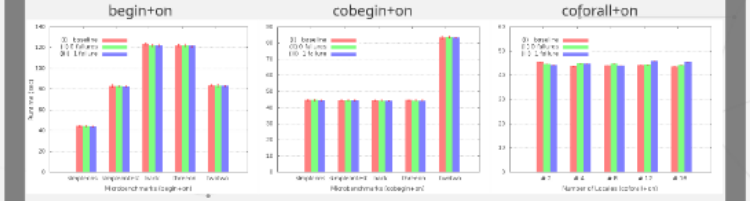

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Fault tolerance property that enables a system to continue operating properly in the event of failure

Resilience integrated design strategy to enable the fault tolerance property of the system

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- achieve **transparent** resilience without requiring user-assistance or source code modifications

Buddy Locales

Resilient Non-Blocking Fork

Non-Blocking Fork

Failure rates

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maintains critical data & survives Failures

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locales branch out, forming the LocaleTree with Locale 0 as root

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Failure Detection

assumption: a node explicitly notifies on its failure

active research on hardware-assisted prediction
- failure prediction/avoidance
  - health metrics
  - external factors (eg. temperature)

GASNet communication API applies strict system-wide abort policy on failures

failure injection/detection needs to be transparent to GASNet

State maintenance

carrying the history of past computations

2 common state-recovery techniques
- checkpointing and forward error recovery

obtain a new correct state and resume execution

use of message logging mechanisms, cost proportional to the number of failures

Limitations

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AM_timeout: function performing recovery on the parent using locally available data

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[1] "Towards Resilient Chapel: Design and Implementation of a Non-Blocking Fork Mechanism for Chapel", K. Panagiotopoulou and H.-W. Loidl, 27th International Conference on Parallel Computing and Distributed Systems (PDCS'15), University of Edinburgh, Edinburgh, Scotland, UK, 2015

Ongoing Work

support for Chapel's data parallel constructs

distributions (distributed memory): Block,Cyclic, BlockCyclic etc.

layouts (shared memory)

Focus : **parallel iterators** [*forall loop on blocked data*]

- buddy locales for redundancy and task re-execution
- under-the-hood remote memory operations

https://github.com/KonstantinosP/chapel

Future Work

- TESTING
- Optimizations
  - cost of remote operations
  - minimize added communication
- Performance improvements
  - replace linked list to tackle O(N) cost of serial lookup operations
  - use of async operations on the data structures
- Investigate portability to other predefined distributions

Longer term goals
- cost model of resilience across multiple configurations
- load balancing policy

Thank you!

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CHIUW'16, IPDPS'16, 23-27 May, Chicago

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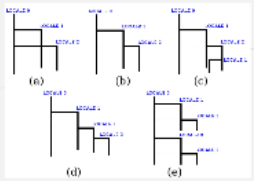

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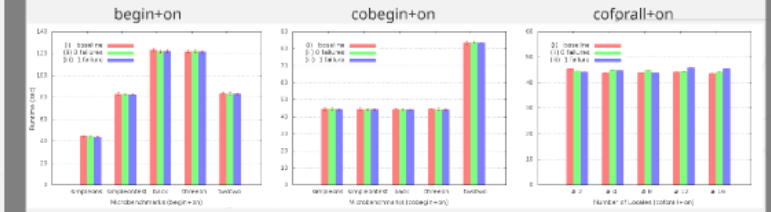

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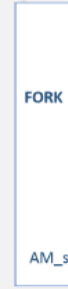
[1] *"Exascale Computing Study: Technology Challenges in Achieving Exascale Systems,"* P. Kogge, K. Bergman et al., 2008.
[2] *"The International Exascale Software Project: A Call to Cooperative Action by the Global High-Performance Community,"* J. Dongarra, P. Beckman, et al., International Journal of High Performance Computing Applications, 2009.
[3] *"High-End Computing Resilience: Analysis of Issues Facing the HEC Community and Path-Forward for Research and Development,"* NNSA, DOE, DARPA, and DOD, cleared by DARPA on 20-01-2010.



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analysis of failure data by Los Alamos National Laboratories [1]

Mean Time Between Failures (MTBF)
between 1 day and 1 month
60% hardware-related factors *PlanetLab, SIGMETRICS 008*

1.7% to **8.6%** annualized disk failure rates

Google's disk failure analysis [2]

a good place to begin
USENIX: The Computer Failure Data Repository (CFDR)
www.usenix.org/cfdr

[1] "A large-scale study of failures in High-Performance Computing systems", B. Schroeder, G. Gibson et al., Dependable and Secure Computing, IEEE Transactions , vol. 7, no. 4, pp. 337–350, 2010

Predictions for exascale

MTBF ~ 20mins for exascale[1]

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[1]"*Facilitating codesign for extreme-scale systems through lightweight simulation*".Engelmann C and Lauer Fr. In Workshop on Application/Architecture Co-design for Extreme-scale Computing (AACEC), 2010.
[2] "*Modeling the impact of checkpoints on next-generation systems*". Oldfield Ron A., Arunagiri S et al., In 24th IEEE Conference on Mass Storage Systems and Technologies, pages 30-46, 2007.

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distributed
parallel

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Resilient Store

maintains critical data &
survives failures

external file system
(eg.ZooKeeper)

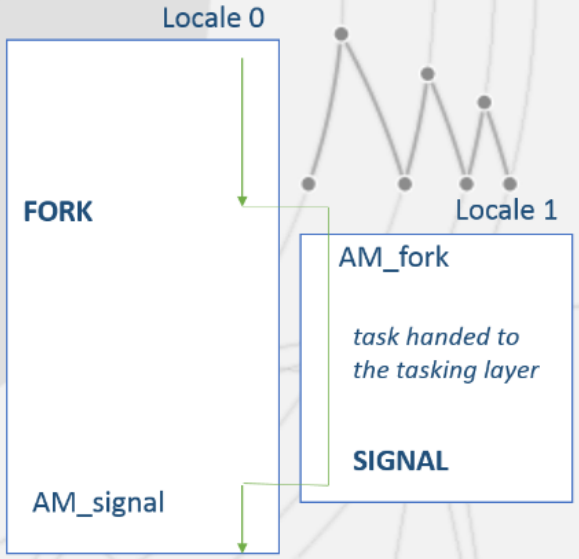
- depends on external components
- optimized existing frameworks

in-memory replication
(eg.RDD's)

- memory overhead
- management of data structures within the RTS
- faster than disk storage
- self-contained applications
- transparent to the programmer

here:
track/store **in-transit messages** on every locale
simple DS (linked lists) for task descriptors,
populated during execution

Blocking Fork



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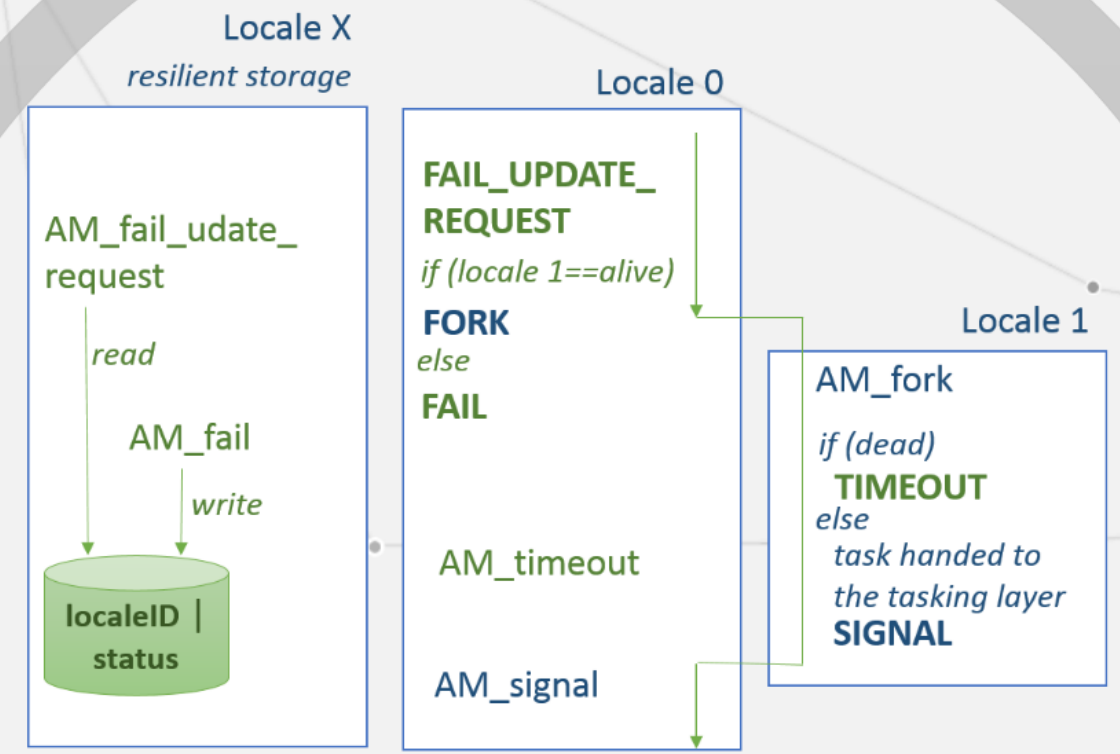

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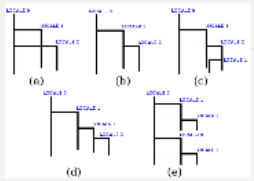

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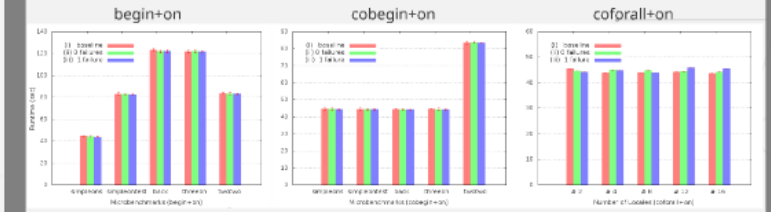

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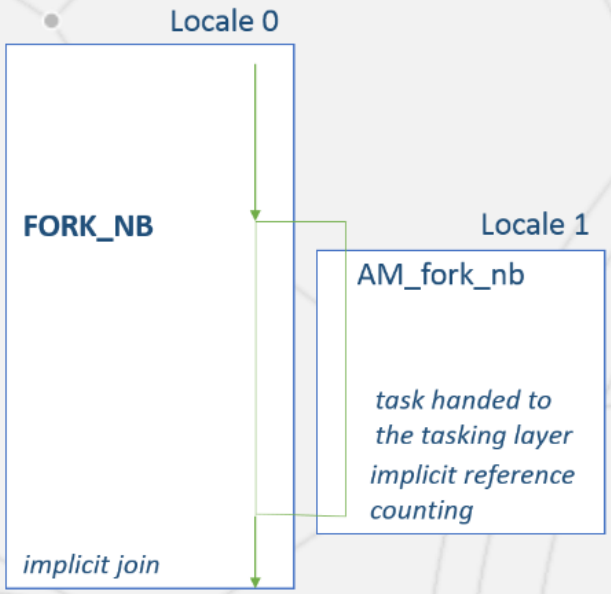

Locale 0 (parent) may EXIT before the failure on Locale 1 (child) occurs

task descriptors on the parent's memory become **inaccessible**

→ need to store task descriptors in advance

UK

Buddy Locales[1]

idea: replicate essential data in the memory of other nodes in the system

parent-buddy communication / data sent to buddies before launching the fork operation

➡ *added communication*

buddy locale is responsible for **adoption** and **recovery**

➡ *potentially unbalanced loads*

# of buddies per locale
buddy selection algorithm

➡ configurable

[1]"*Fault-tolerance techniques for high-performance computing*". Herault T, and Robert Y. Springer, 2015.

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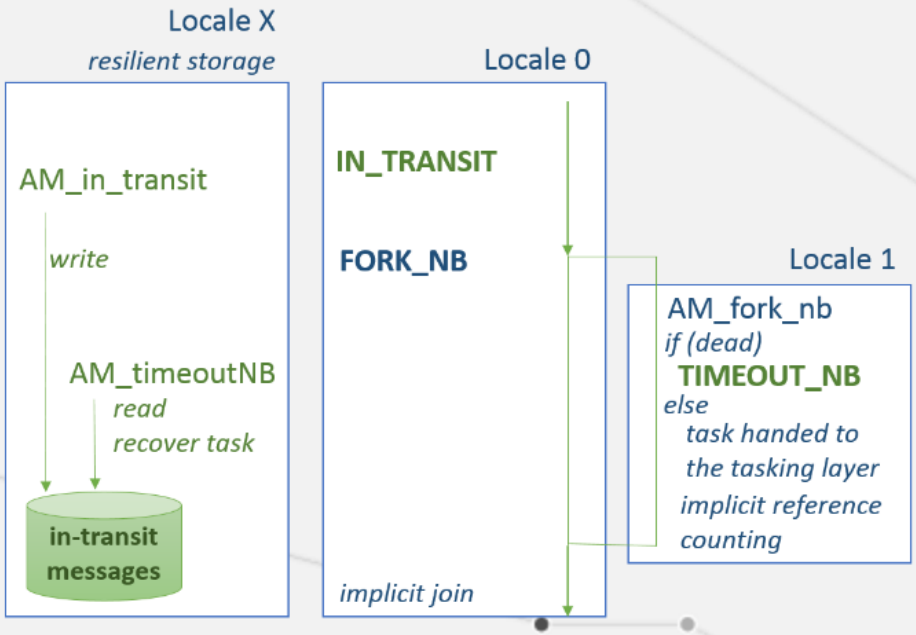

IN_TRANSIT parent → buddy locale(s)
buddy stores task descriptor
before launching remote fork

TIMEOUT_NB child → buddy locale(s)
buddy retrieves task descriptor &
launches recovery

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such HW capability can be represented by a failure notification message on the communication layer

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[1] "*Critical Event Prediction for Proactive Management in Large-scale Computer Clusters*," R. K. Sahoo, A. J. Oliner et al., in Proceedings of the Ninth ACM SIGKDD International Conference on Knowledge Discovery and Data Mining. ACM, 2003, pp. 426–435.

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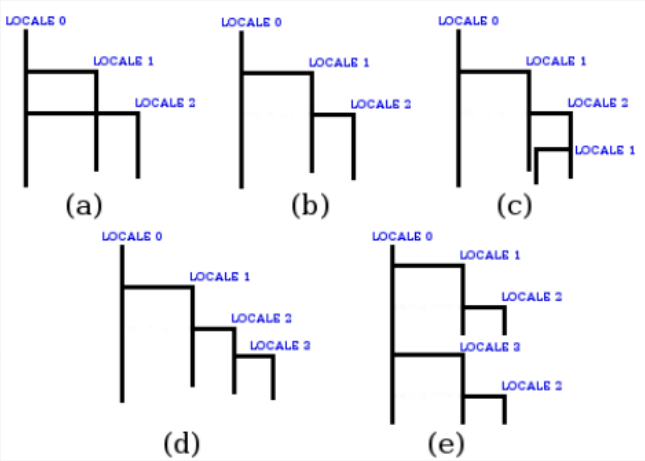

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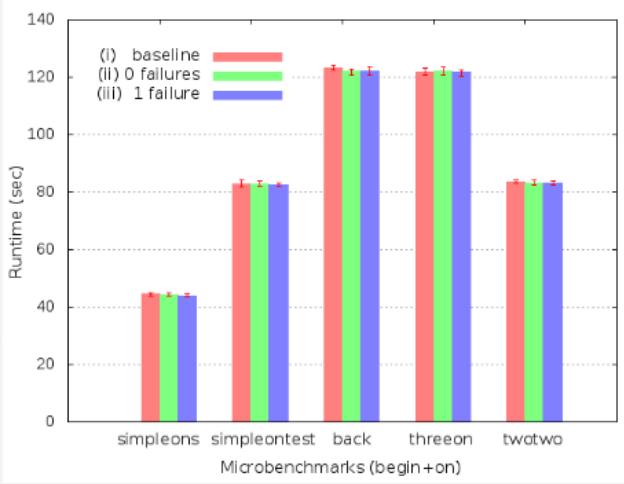

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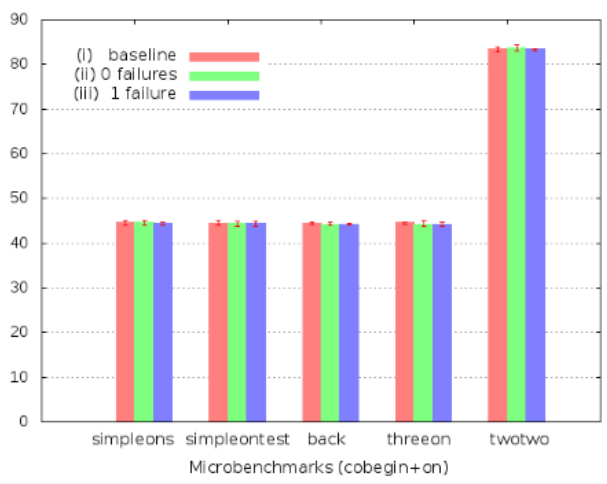

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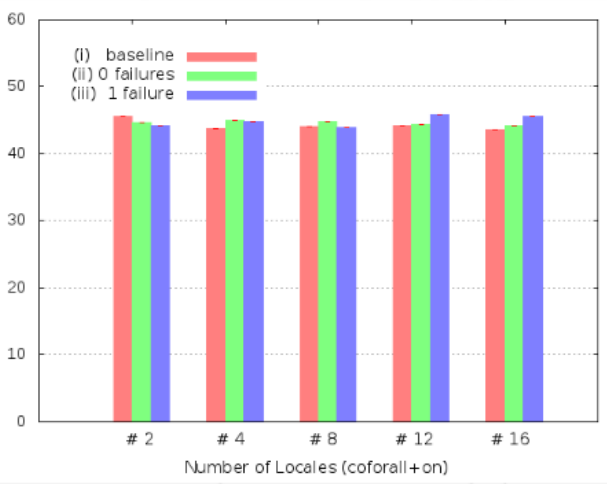

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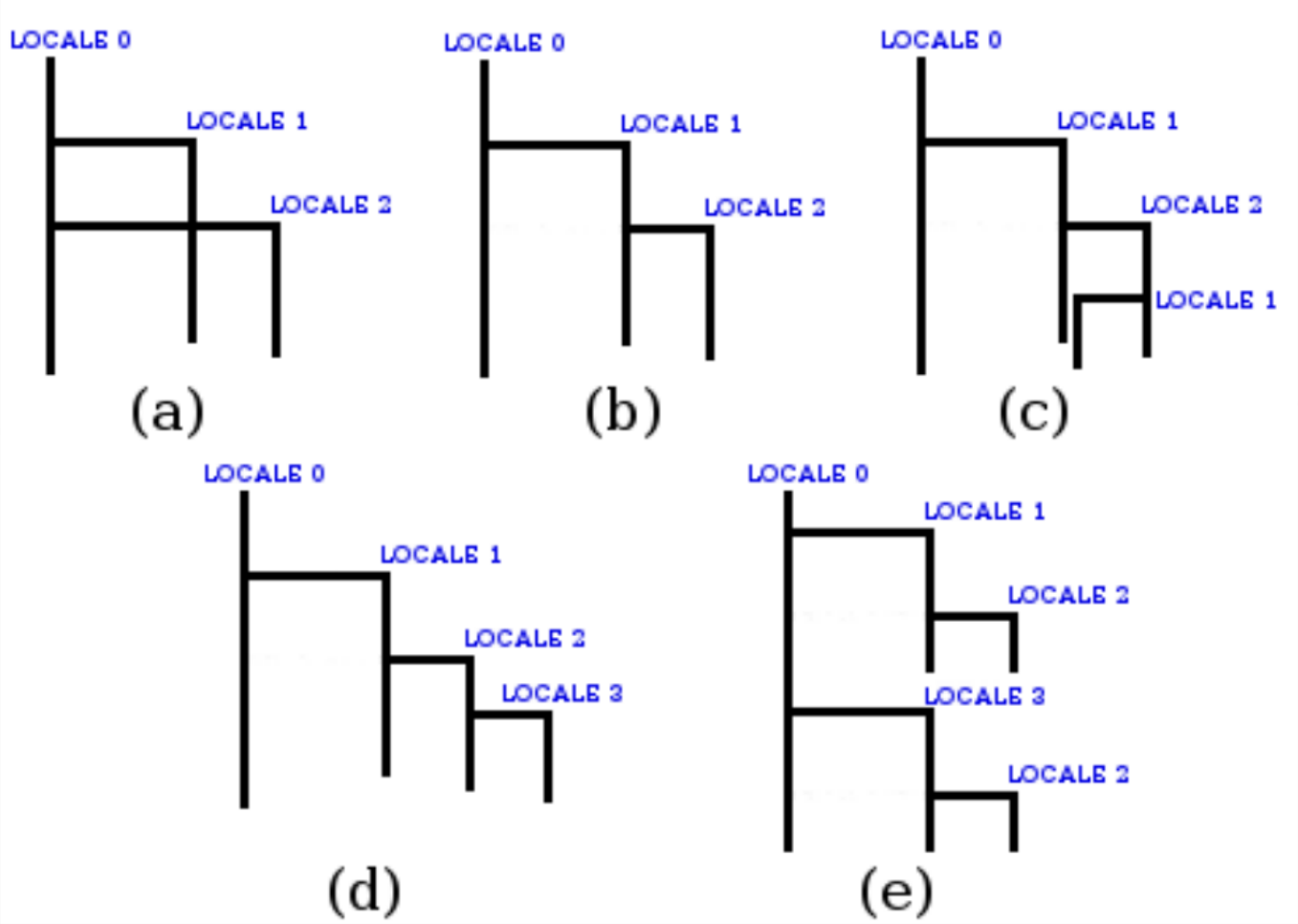

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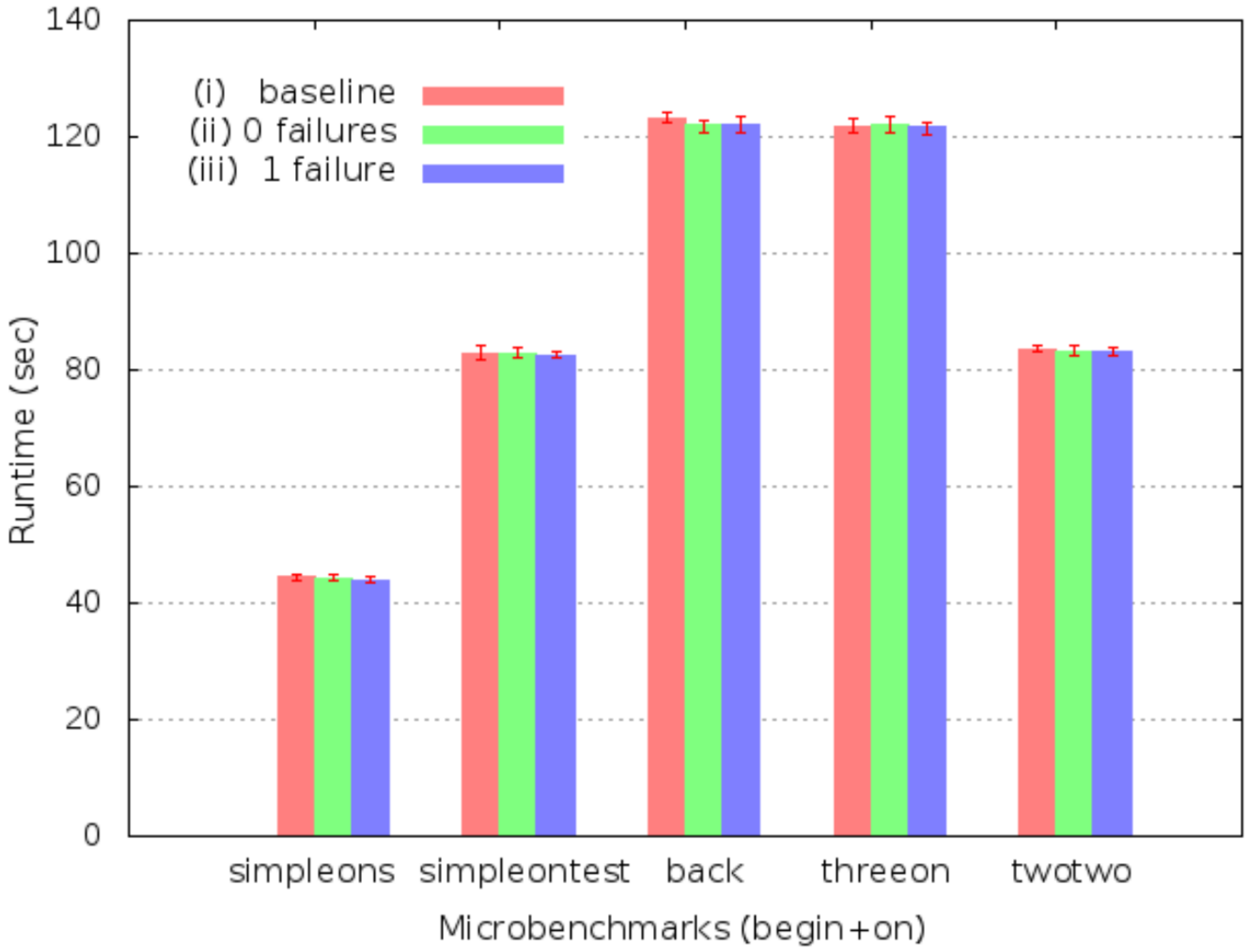
140
120
100
80
60
40
20
0
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simpleons
simpleontest
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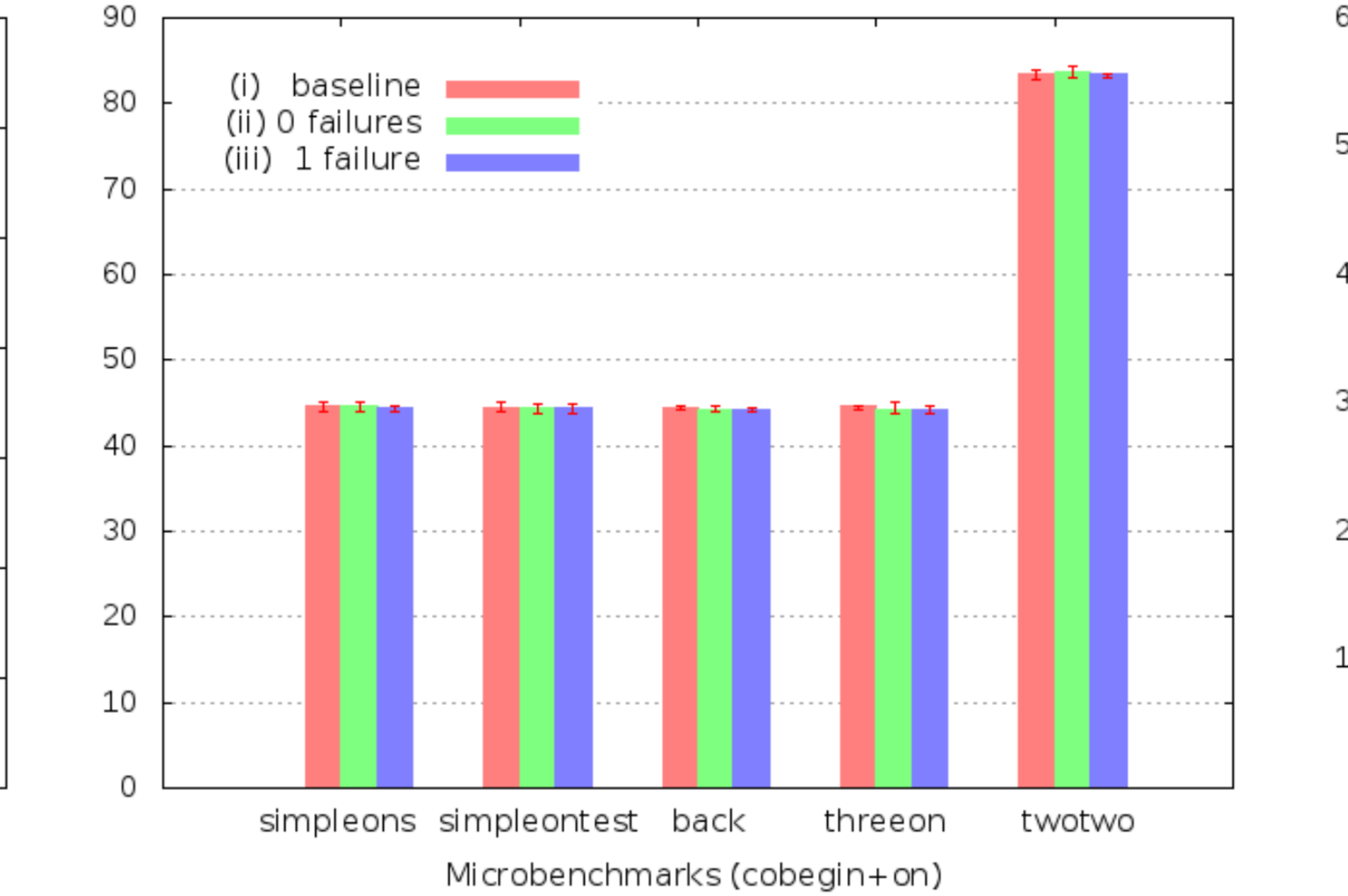
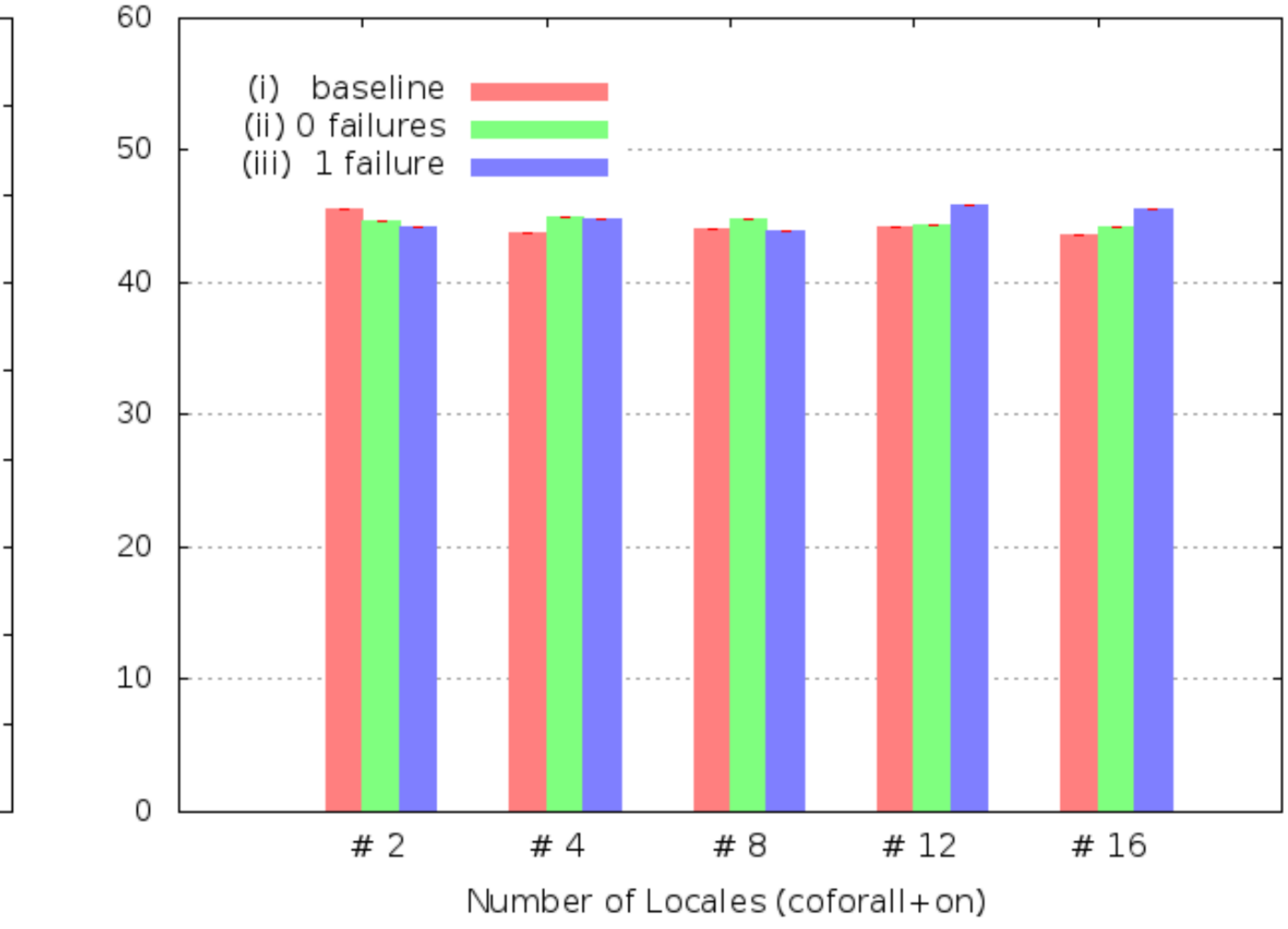
Microbenchmarks (begin+on)

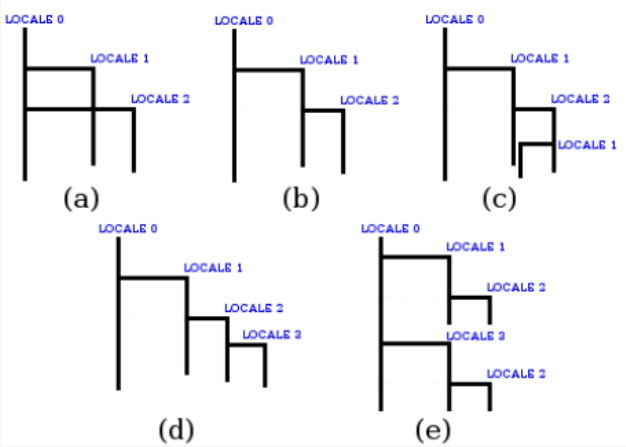
cobegin+on


(i) baseline
(ii) 0 failures
(iii) 1 failure
90
80
70
60
50
40
30
20
10
0
simpleons
simpleontest
back
threeon
twotwo
Microbenchmarks (cobegin+on)

coforall+on

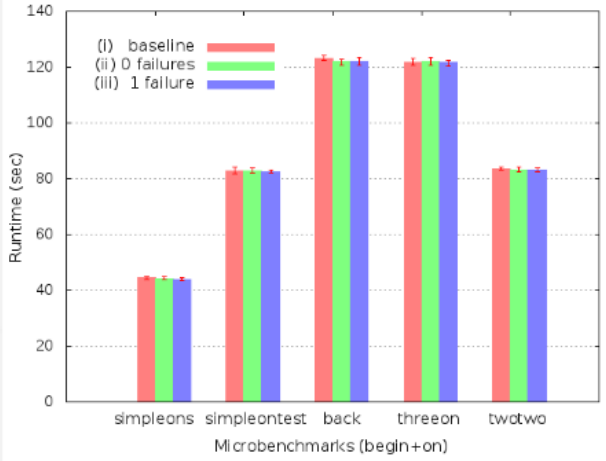

60
50
40
30
20
10
0
(i) baseline
(ii) 0 failures
(iii) 1 failure
2
4
8
12
16
Number of Locales (coforall+on)

Evaluation Results

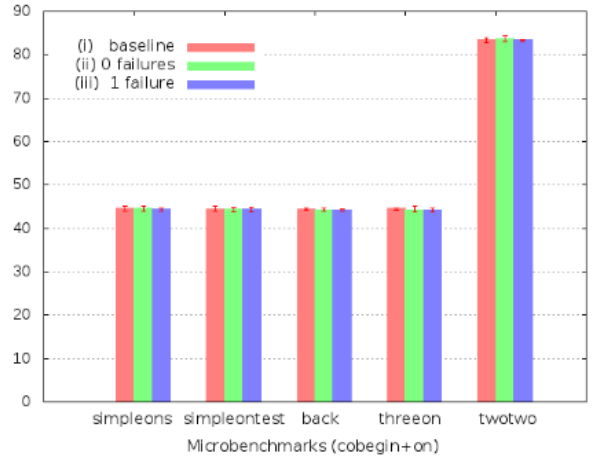


constructed micro-benchmarks

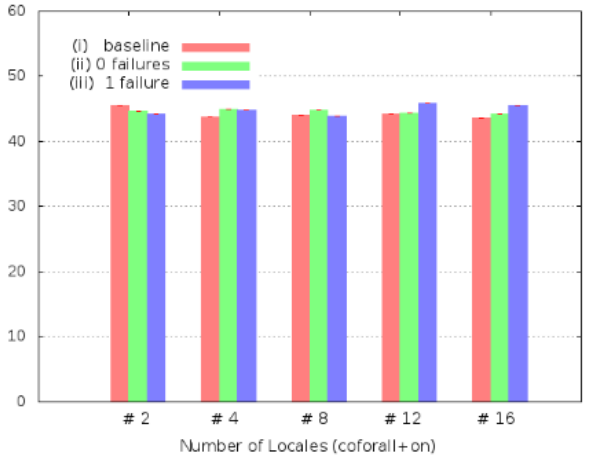
begin+on



cobegin+on



coforall+on



*System specs:16 nodes of a 32-node Beowulf cluster connected via Gigabit ethernet network, with each node consisting of two quad-core Xeon E5506 2.13GHz, 12GB of main memory and three-layered cache memory topology.

Ongoing Work

support for Chapel's data parallel constructs

distributions (distributed memory)
Block,Cyclic, BlockCyclic etc.

layouts (shared memory)

Focus : **parallel iterators** [***forall*** *loop on blocked data*]

- buddy locales for redundancy and task re-execution
- under-the-hood remote memory operations

https://github.com/konsP/chapel

Future Work

- T E S T I N G
- Optimizations
  - cost of remote operations
  - minimize added communication
- Performance improvements
  - replace linked list to tackle O(N) cost of serial lookup operations
  - use of async operations on the data structures
- Investigate portability to other predefined distributions

Longer term goals

- cost model of resilience across multiple configurations
- load balancing policy

Thank you!

Questions?

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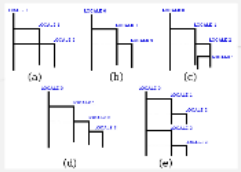
Transparently Resilient Task Parallelism for Chapel

Konstantina Panagiotopoulou, Hans-Wolfgang Loidl

Heriot-Watt University, Edinburgh, UK

Evaluation Results



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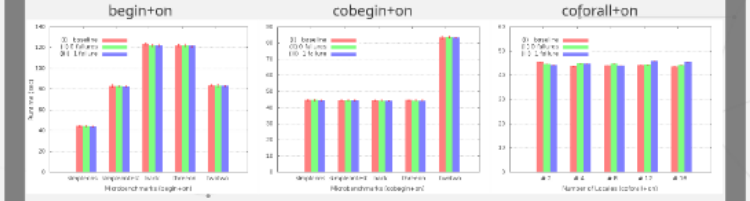

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Resilience

Fault tolerance property that enables a system to continue operating properly in the event of failure

Resilience integrated design strategy to enable the fault tolerance property of the system

Transparent Resilience for Chapel

GOAL
- allow distributed long-running Chapel applications to terminate successfully in the presence of hardware failure of participating nodes
- achieve **transparent** resilience without requiring user-assistance or source code modifications

Buddy Locales

Resilient Non-Blocking Fork

Non-Blocking Fork

Failure rates

Chapel's Task Parallel constructs

```
// create a fire-and-forget task
begin async_task();
reg_task();

// create one task per statement
cobegin {
 producer(1);
 producer(2);
 consumer(1);
} // implicit join

// create a task per iteration
coforall t in 0..#numTasks {
  async_task();
} // implicit join
```

on construct

"invoke work on remote locales"

```
on Locales[1] do
  remote_task(); //on Loc1
local_task(); // on Loc0
```

translates to a blocking fork operation

```
begin on Locales[1] do
  async_remote_task(); //on Loc1
local_task(); // on Loc0
cobegin on...
coforall on...
```

translate to non-blocking fork operations

Resilient Store

maintains critical data & survives Failures

Blocking Fork

parent locale waits on completion of the remote task on the child locale

simplest case for recovery

data already available on the parent -> no need for replication

Blocking Fork

recovery from failure is handled on the parent locale
- data retrieved from local memory

locales branch out, forming the LocaleTree with Locale 0 as root

parent failures can be dealt with as child failures one level higher on the tree

- failure of Locale 0 is unrecoverable

Failure Detection

assumption: a node explicitly notifies on its failure

active research on hardware-assisted prediction
- failure prediction/avoidance
  - health metrics
  - external factors (eg. temperature)

GASNet communication API applies strict system-wide abort policy on failures

failure injection/detection needs to be transparent to GASNet

State maintenance

carrying the history of past computations

2 common state-recovery techniques
- checkpointing and forward error recovery

obtain a new correct state and resume execution

use of message logging mechanisms, cost proportional to the number of failures

Limitations

Resilient Blocking Fork[1]

AM_timeout: function performing recovery on the parent using locally available data

AM_fail(_update) : functions to query and update centrally stored (Loc 0) information on the status of nodes

[1] "Towards Resilient Chapel: Design and Implementation of a Non-Blocking Fork Mechanism for Chapel", K. Panagiotopoulou and H.-W. Loidl, 27th International Conference on Parallel Computing and Distributed Systems (PDCS'15), University of Edinburgh, Edinburgh, Scotland, UK, 2015

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CHIUW'16, IPDPS'16, 23-27 May, Chicago