Adoption Protocols for Fanout-Optimal Fault-Tolerant Termination Detection

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February 26, 2013

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Fanout-Optimal

Fault-Tolerant

Termination Detection

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Termination Detection $\longrightarrow$ What is it?

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Previous work

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Fanout-Optimal	$\longrightarrow$	Theoretical bounds
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		Trio of protocols:
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  - idle $\equiv$ passive

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  - Runtimes with message-driven execution[‡]

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[‡] Jeremiah Willcock, Torsten Hoefler, Nicholas Edmonds, Andrew Lumsdaine. *Active pebbles: parallel programming for data-driven applications*. Proceedings of the international conference on Supercomputing. ICS'11.

Termination Detection

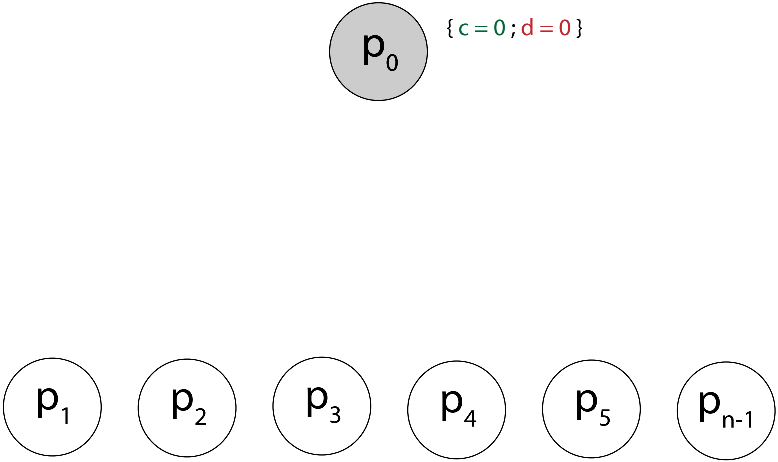
→ Algorithms

- Many different variants (with different tradeoffs)
  - Parental responsibility[§]
  - Wave-based
  - Credit-recovery

[§] Edsger W. Dijkstra, C.S. Scholten. *Termination detection for diffusing computations.* Information Processing Letters. 1980.

Termination Detection

→ Algorithm Overview : Parental Responsibility



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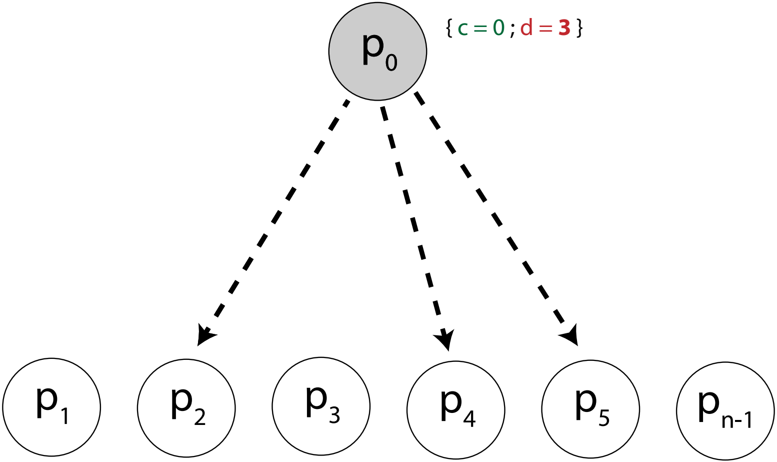

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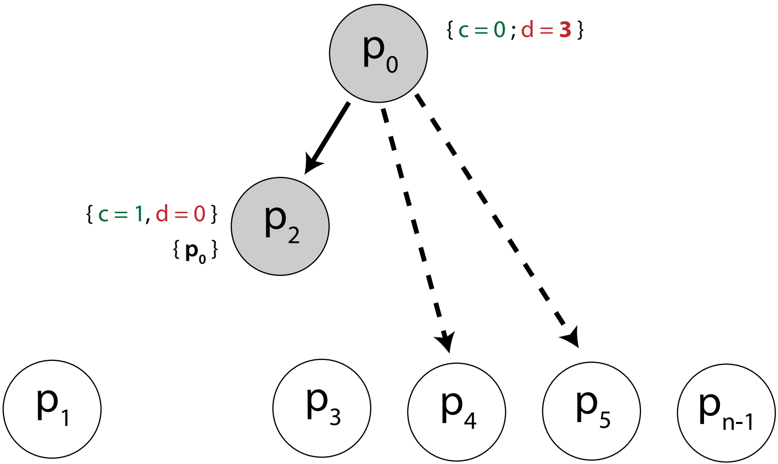

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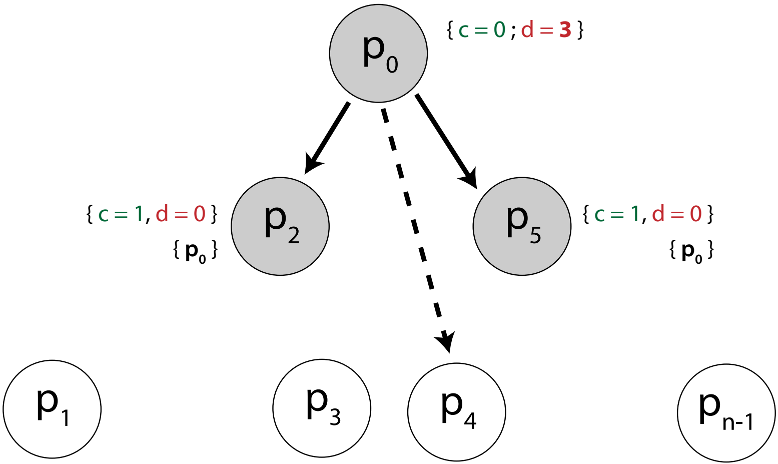

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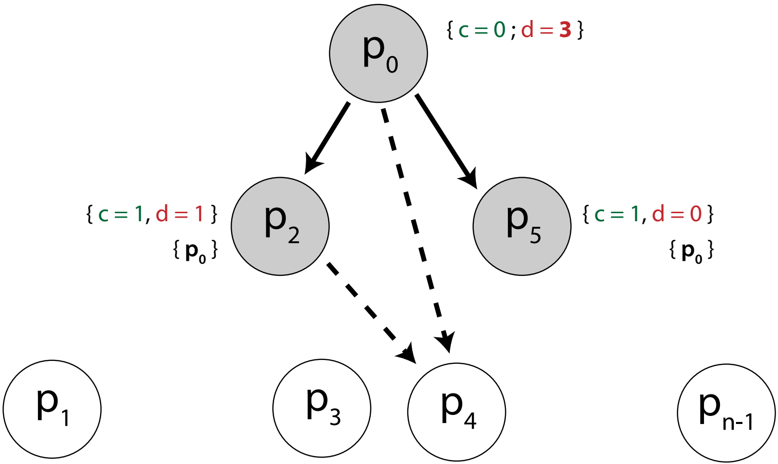

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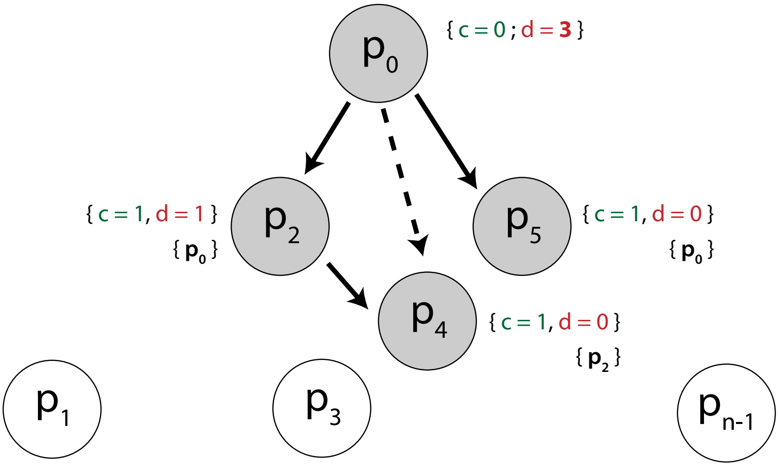

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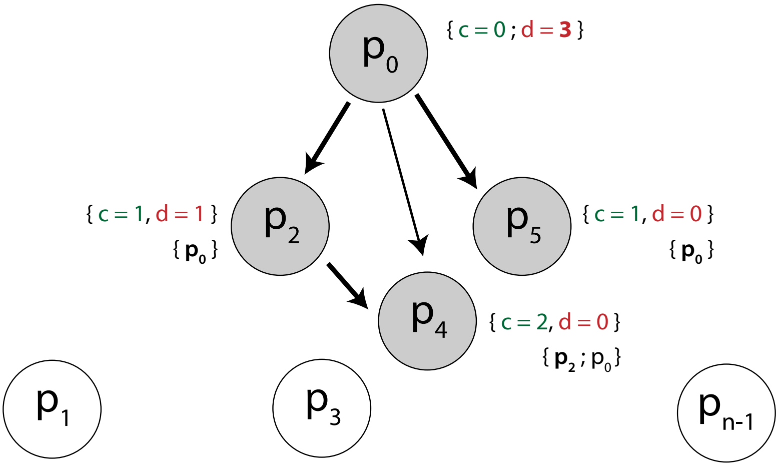

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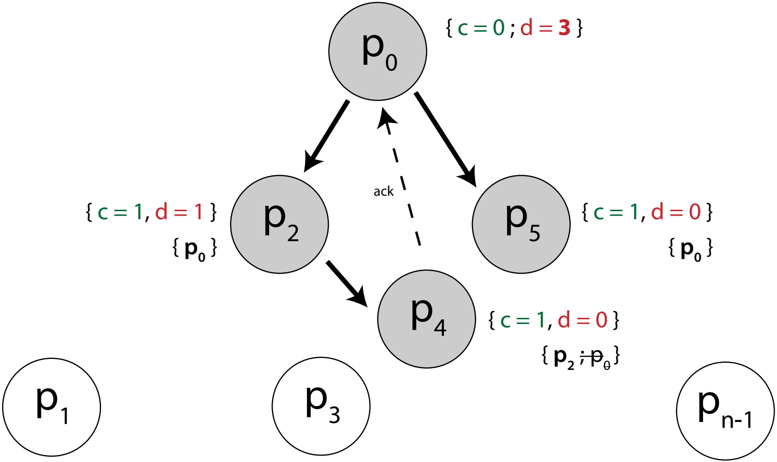

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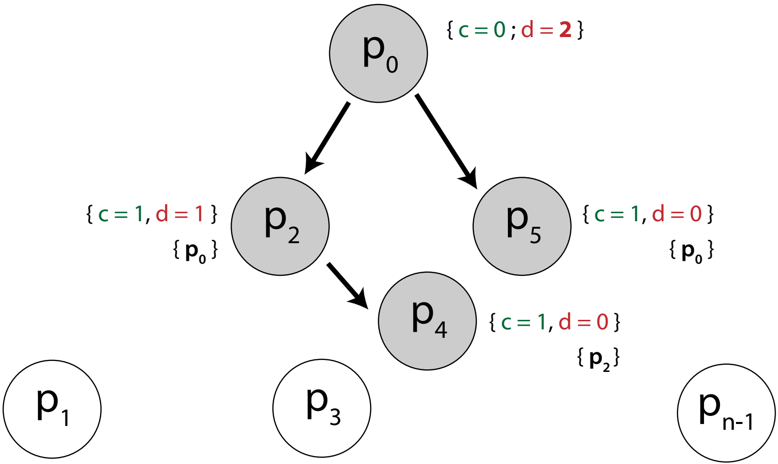

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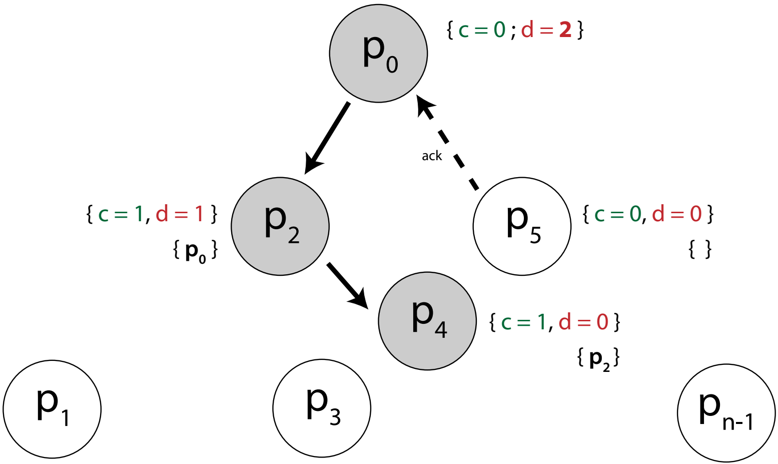

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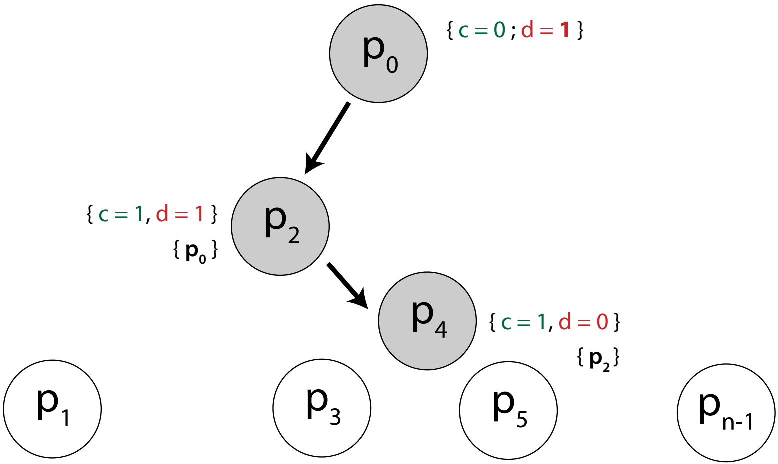

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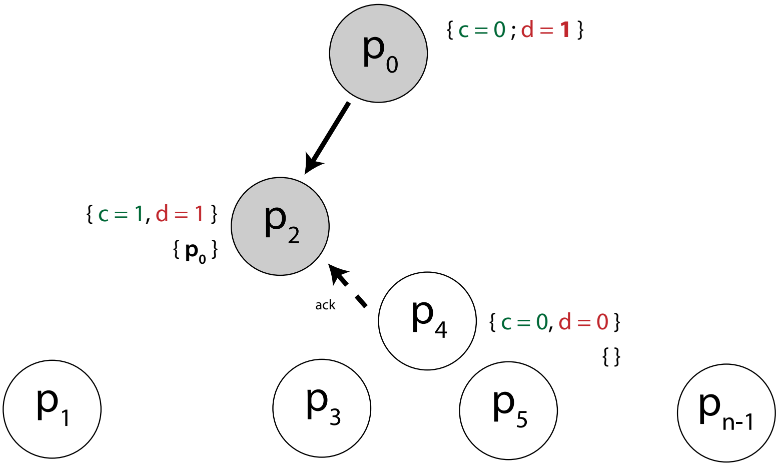

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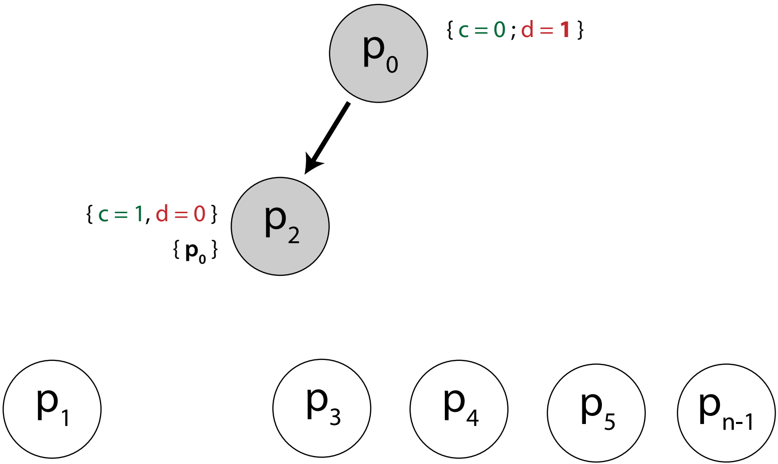

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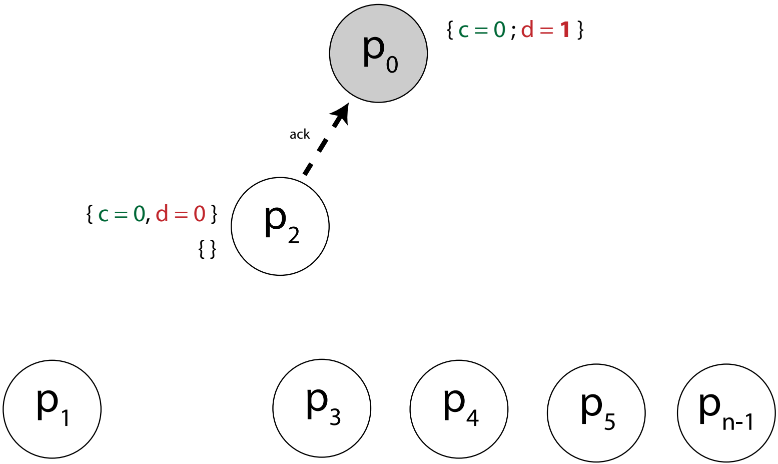

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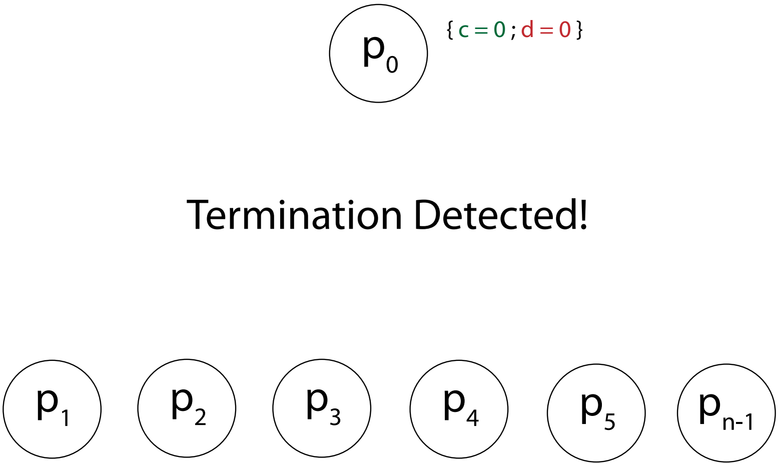

git://charm.cs.illinois.edu/terminator.git

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General C++ and Java library

`git://charm.cs.illinois.edu/terminator.git`

Implemented in three parallel runtime systems

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Being made fault-tolerant based on this work

Fault-Tolerant Termination Detection

→ Problem Description

- Approaches to fault-tolerance
  - General runtime-system support: checkpointing, message-logging, etc.

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  - Algorithm-specific (checksum-based approaches for math libraries)
  - Component-specific: runtime system is composed of a set of self-healing components that all handle faults in their own optimized way — so-called *scale invariance*[¶]

[¶] Al Geist and Christian Engelmann. *Development of Naturally Fault Tolerant Algorithms for Computing on 100,000 Processors*. 2002.

Fault-Tolerant Termination Detection

$\rightarrow$ Component-specific

- Assume ecosystem is fault tolerant
  - Application can recover from faults
  - Other runtime system components are fault-tolerant
  - Termination can be handled as a modular component

Fault-Tolerant Termination Detection

→ Previous work

- Distributed computing
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  - Has low overhead on forward execution

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Fault-Tolerant Termination Detection

→ Goals for HPC

- Low overhead during forward execution
- Expect to encounter faults that only impact a small subset of the processes
- Build a scalable algorithm for recovery

Termination Detection

→ Optimality

- Parental responsibility algorithms
  - *Message-optimal*: in the worst case, they send the lower-bound on signal count**
  - Where the lower bound is $\mathcal{O}(m)$, and m is the total number of application messages

**K. Mani Chandy and Jayadev Misra. *How processes learn*. In Proceedings of the forth annual ACM symposium on Principles of Distributed Computing (PODC '85).

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  - The fault-tolerance algorithms we present are fanout-optimal

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  - *Fail-flush*: a system notification indicating that in-flight messages from a failed process have all been received

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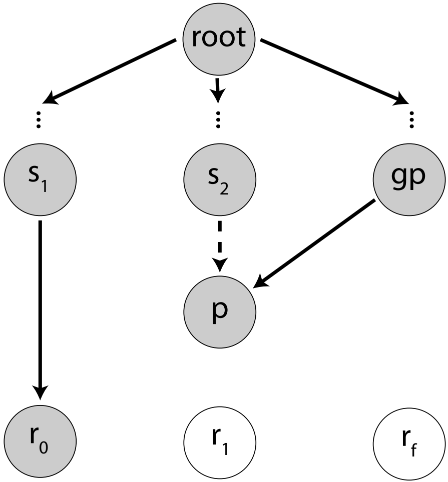

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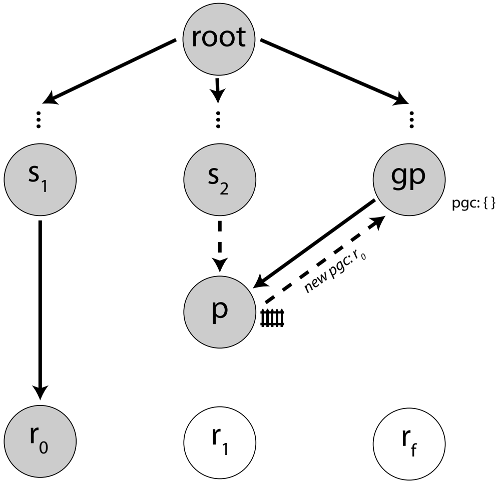

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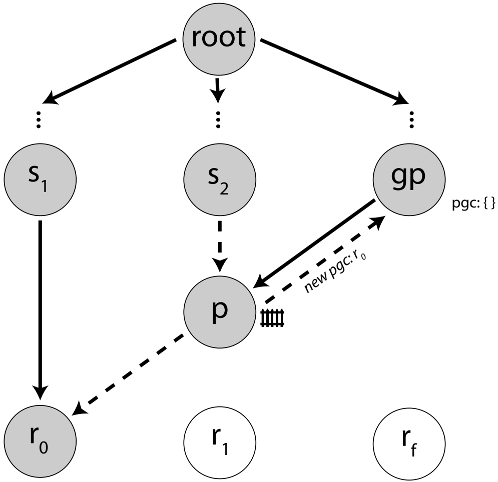

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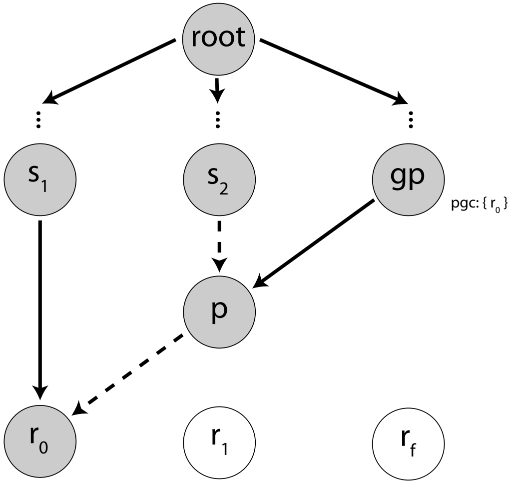

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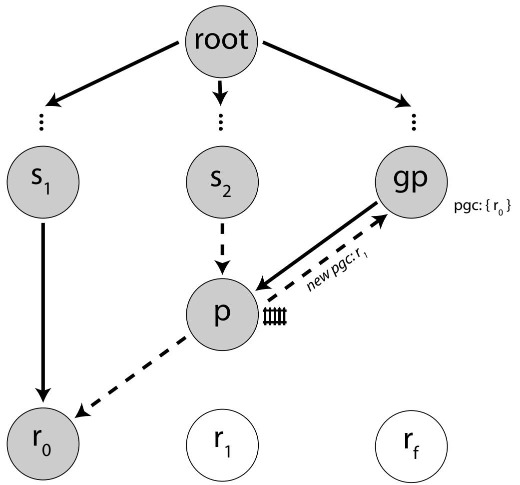

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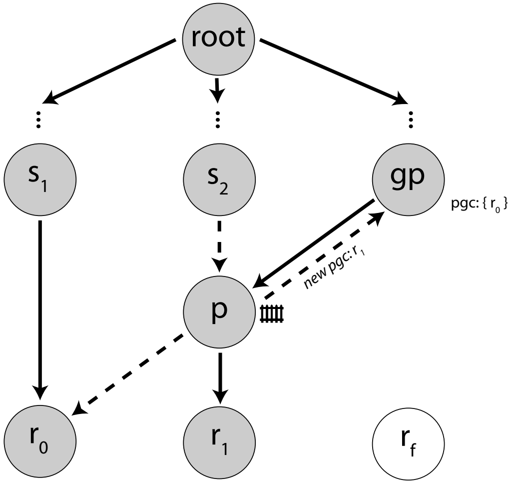

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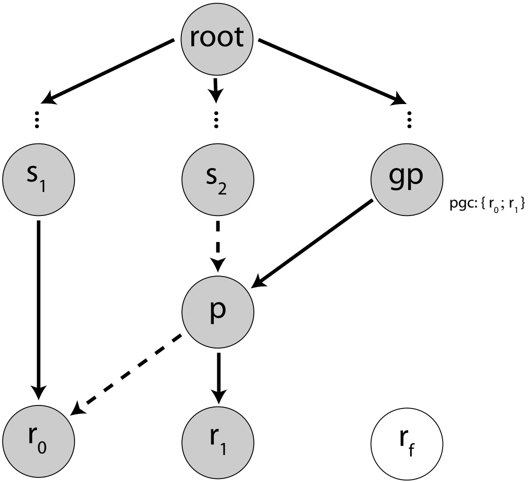

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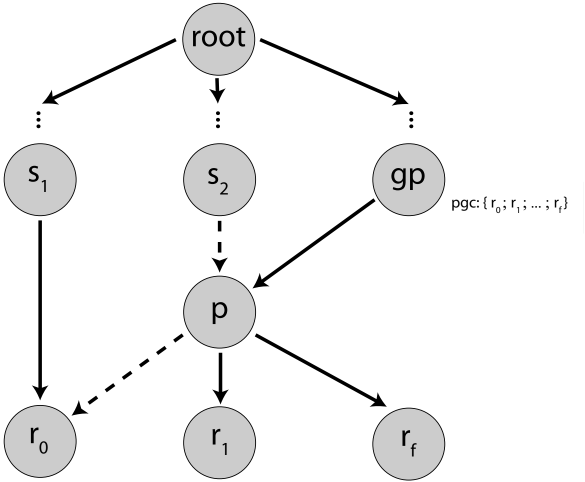

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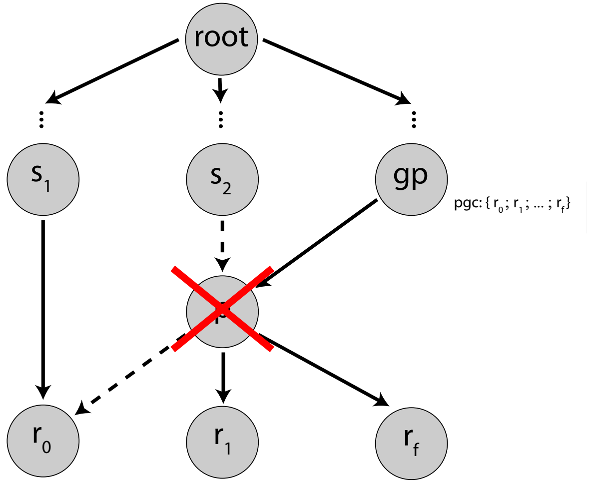

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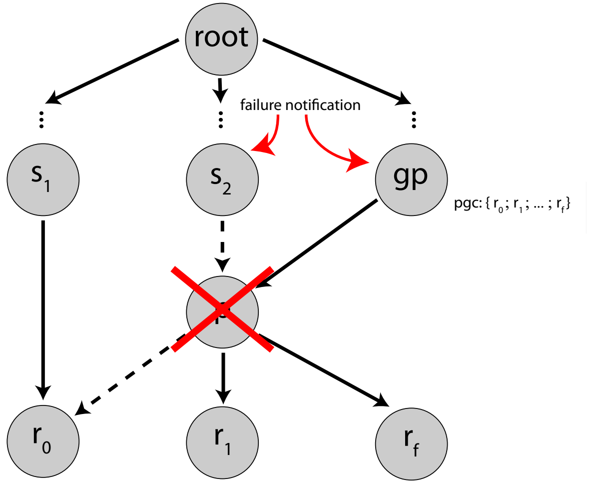

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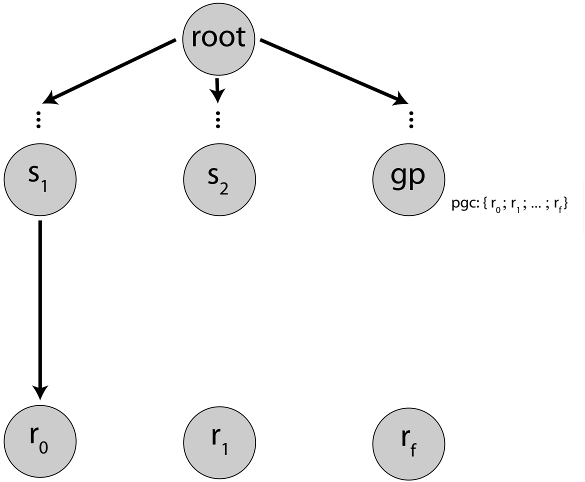

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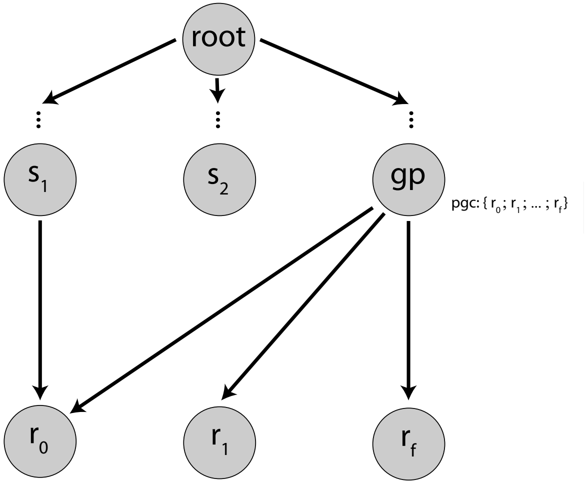

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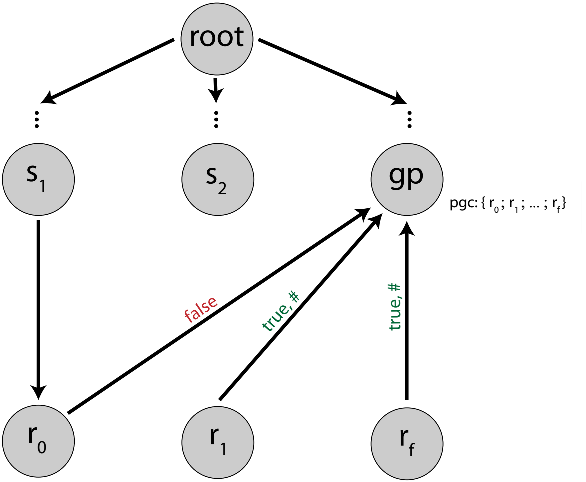

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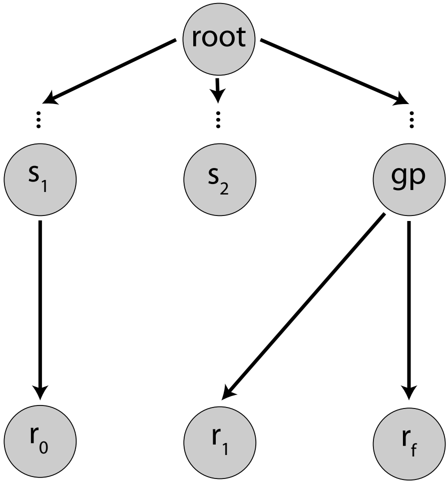

Termination Detection

→ The INDEP fault-tolerance protocol

- Tolerates all single-process failures

Termination Detection

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- What multi-process failures does it not tolerate?

Termination Detection

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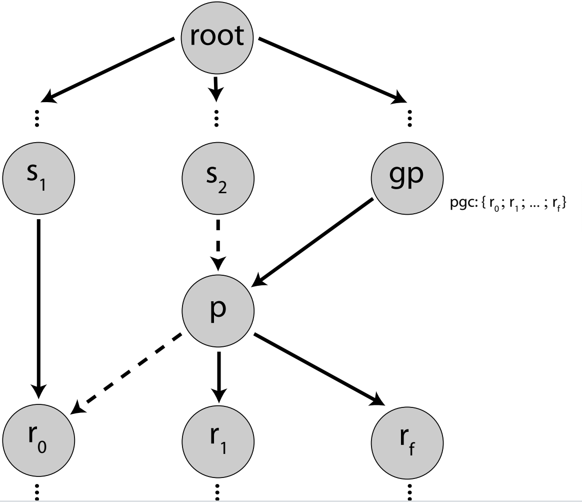
Termination Detection

→ The INDEP fault-tolerance protocol

- Tolerates all single-process failures
- What multi-process failures does it not tolerate?
  - INDEP will tolerate all failures except for parent-child pairs...
  - But, INDEP cannot detect this case, so it has to fail conservatively if the failure set has communicating pairs in it

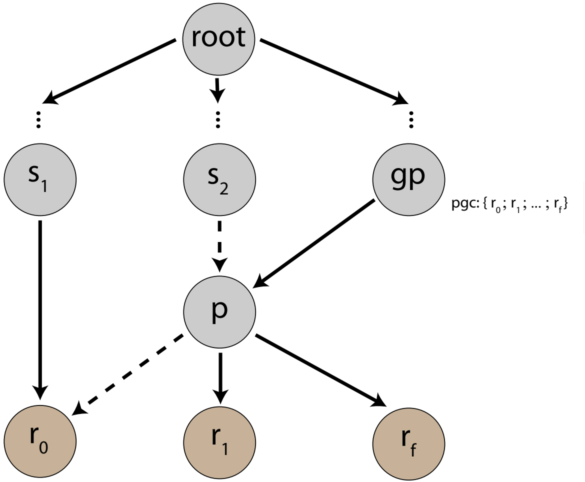
Termination Detection

→ The INDEP fault-tolerance protocol



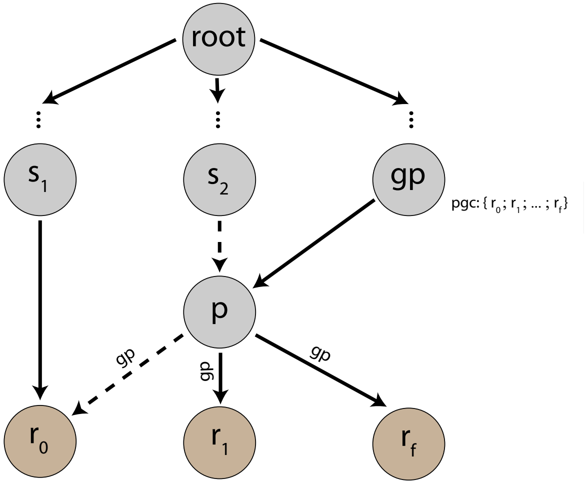
Termination Detection

→ **The** RELLAZY **and** RELEAGER **protocols**



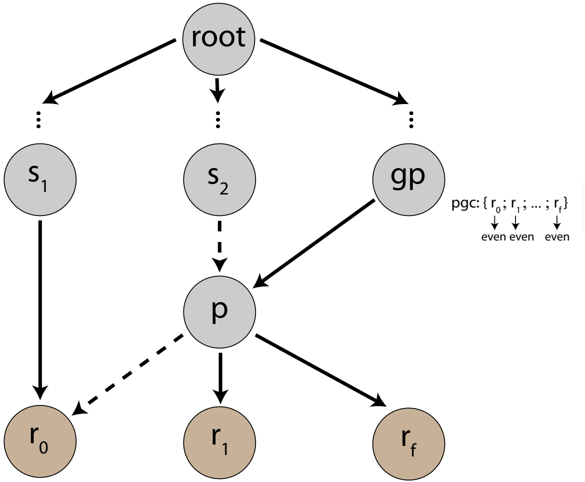
Termination Detection

→ **The** RELLAZY **and** RELEAGER **protocols**



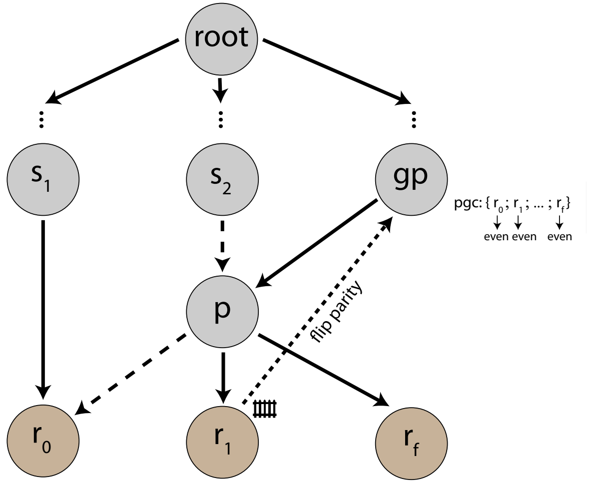
Termination Detection

→ The RelLazy and RelEager protocols



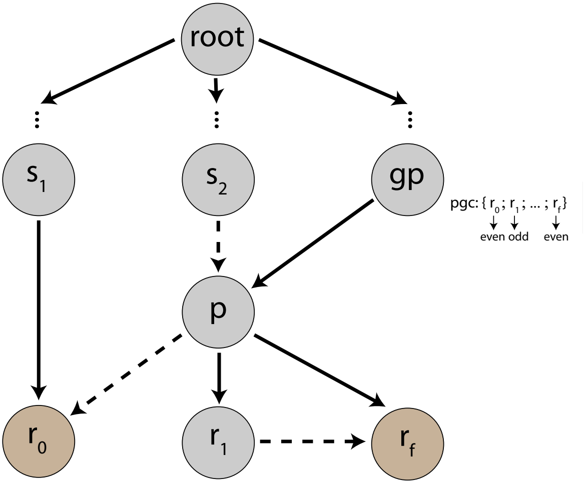
Termination Detection

→ The RelLazy and RelEager protocols



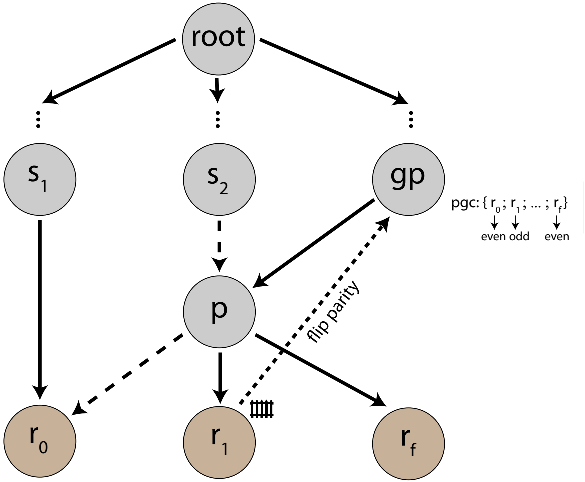
Termination Detection

→ **The RelLazy and RelEager protocols**



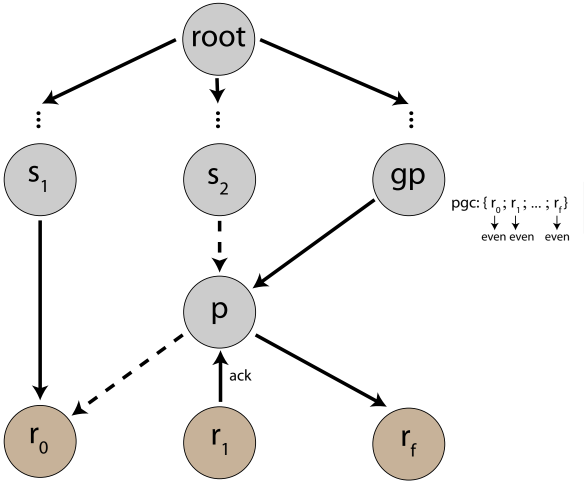
Termination Detection

→ The RelLazy and RelEager protocols



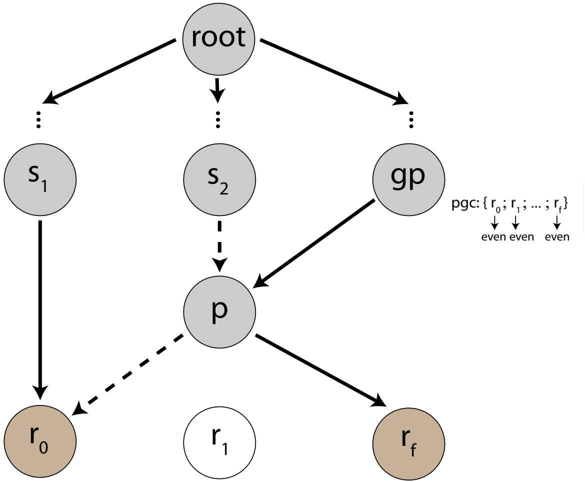
Termination Detection

→ The RELLAZY and RELEAGER protocols



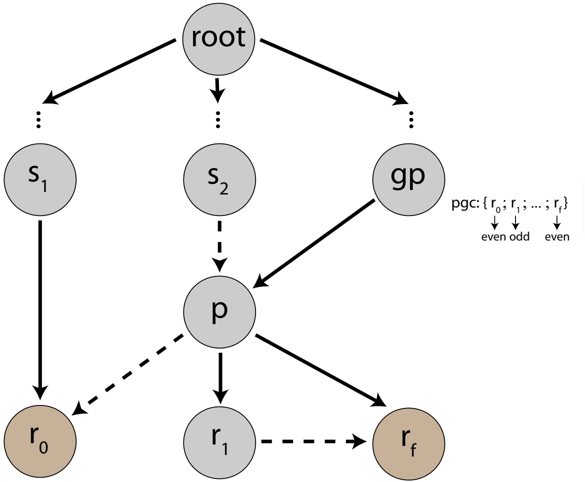
Termination Detection

→ **The RelLazy and RelEager protocols**



Termination Detection

→ The RelLazy and RelEager protocols



Termination Detection

→ Probability Model and Survivability

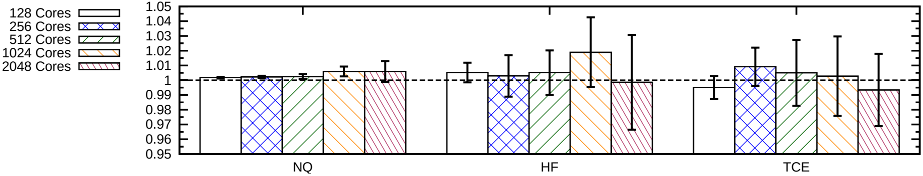
Nodes Failed	Fault (%)
1	92.30
2	3.672
3	0.942
4	0.753
5	0.565
6	0.094
7	0.094
8	0.377
9	0.094
10	0.188
11	0.188
15	0.282
18	0.094
26	0.094
86	0.094
126	0.094

Protocol		Survivability* (%)
INDEP	$f = 2$	99.32
	$f = 8$	98.63
	$f = 32$	97.47
	$f = 512$	93.21
REL*		99.50

*Assuming a 1024-node job

Termination Detection

→ Empirical Results



- Ratio of execution time without FT compared to using the REL* protocols
- Sample size of 24, using a Student's t-test, error bars represent standard error at 99% confidence
- Using distributed-memory work stealing — NQueens (NQ), HF (Hartree-Fock), TCE (Tensor Contraction Expressions)

Termination Detected!

`git://charm.cs.illinois.edu/terminator.git`