Smart Redundancy for Distributed Computation

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How do I compute a function using Byzantine machines?

How do I send you a message over a noisy channel?

Environment model

A pool of network nodes

- some nodes are Byzantine
- Byzantine node identity and rate are unknown
- nodes may join, leave, fail, and become reliable

Smart redundancy: maximize task reliability for a given resource cost

Applicable to problems with many independent subtasks that can be executed out of order.

Example

- MapReduce / Hadoop [Dean and Ghemawat 2004]
- Globus Grid Toolkit [Foster et al. 2001]
- BOINC [Korpela et al. 1996]

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Crowdsourcing applications too

- reCAPTCHA [von Ahn et al. 2008]
- ESP Game [von Ahn and Dabbish 2004]
- FoldIt [Baker 2009]
- software verification [Schiller and Ernst 2010]

Voting redundancy

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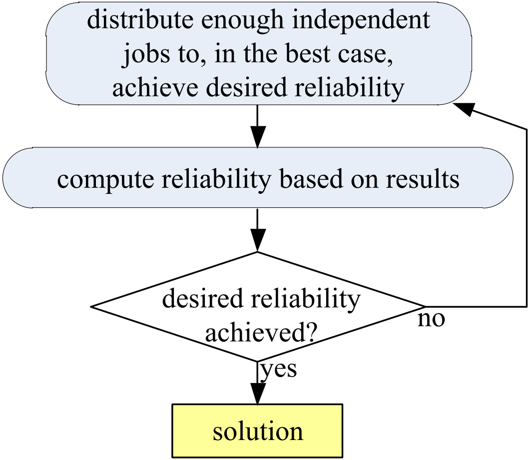
- If we ask 3 nodes, the system reliability will be:
  $1 - 0.3^3 - 3\left(0.3^2\right)0.7 \approx 0.84$
- 19 nodes have to vote to get 0.97 reliability:
  $1 - \sum_{i=10}^{19} \binom{19}{i} 0.3^i 0.7^{19-i} \approx 0.97$

Smart redundancy



main idea: only deploy jobs if you need them

Smart redundancy example execution

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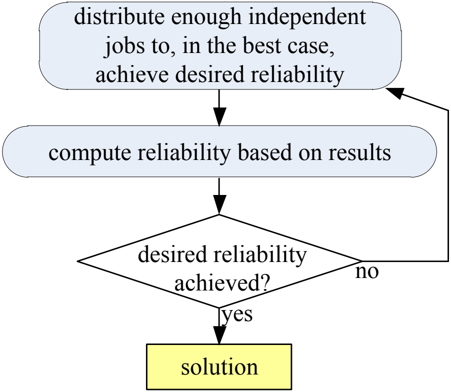

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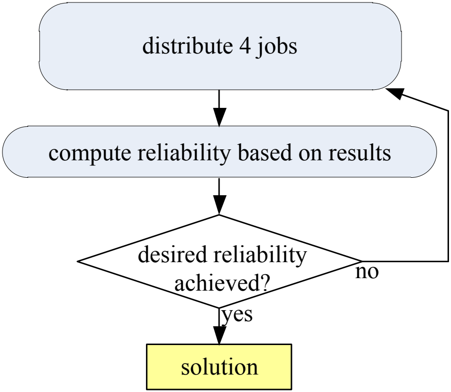

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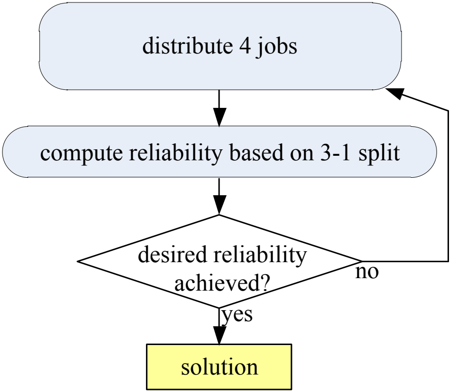

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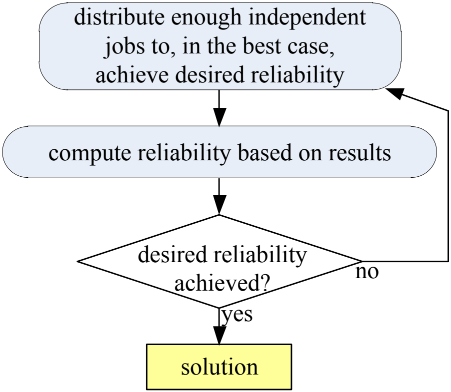

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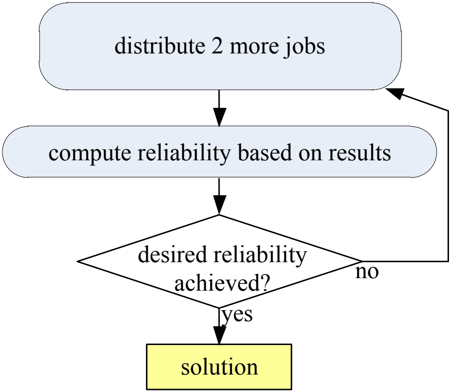

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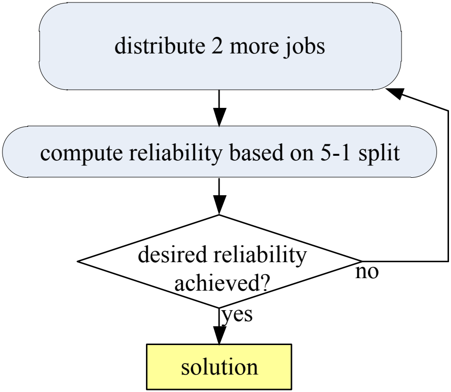

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smart redundancy
(1) assumes best case and asks the minimum number of nodes
(2) asks more after learning how reality differs from best case.

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Bayes theorem implies that given an a-b split of answers, only the difference affects the reliability.

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room 1

Flip a 70% / 30% coin 4 times get 4 heads and 0 tails.

room 2

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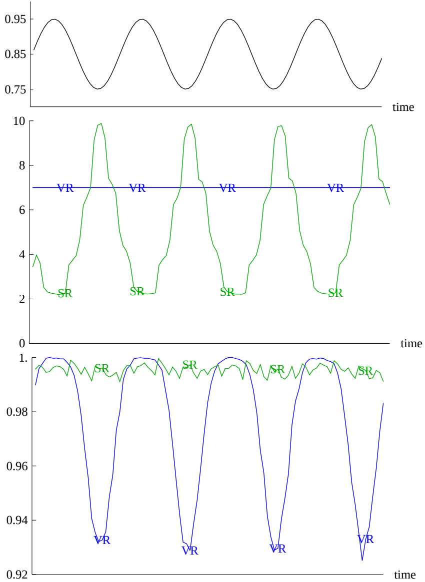
Inject redundancy only when it is needed

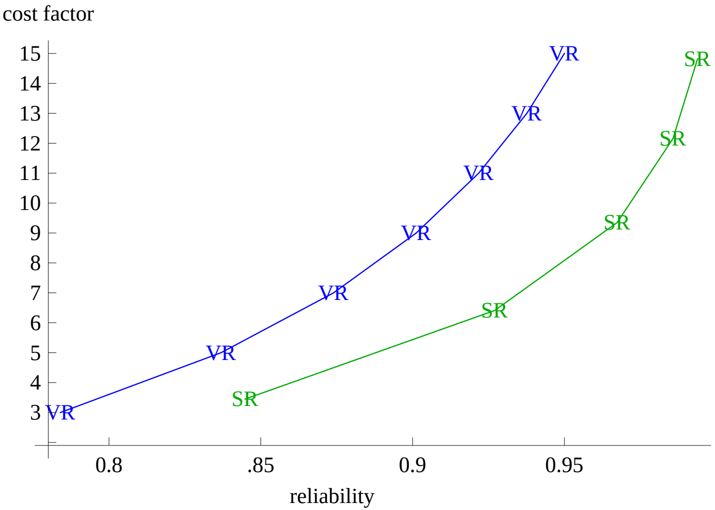
node reliability:

cost factor:

system reliability:

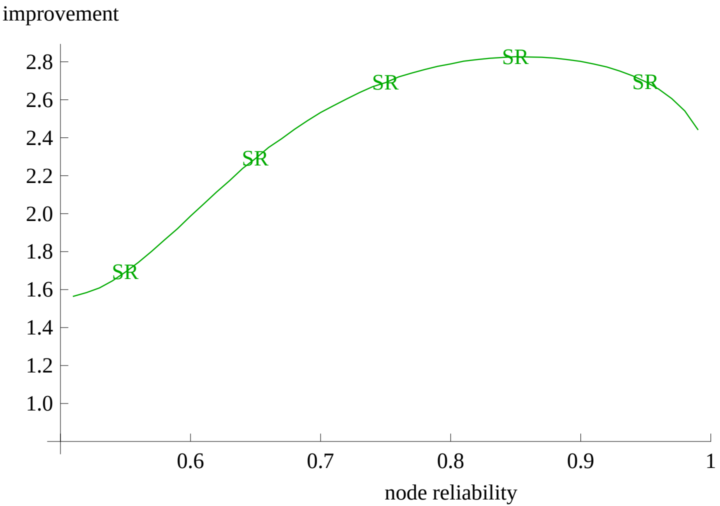


Smart always outperforms voting redundancy



node reliability is 0.7

Reliable nodes lead to greater benefits



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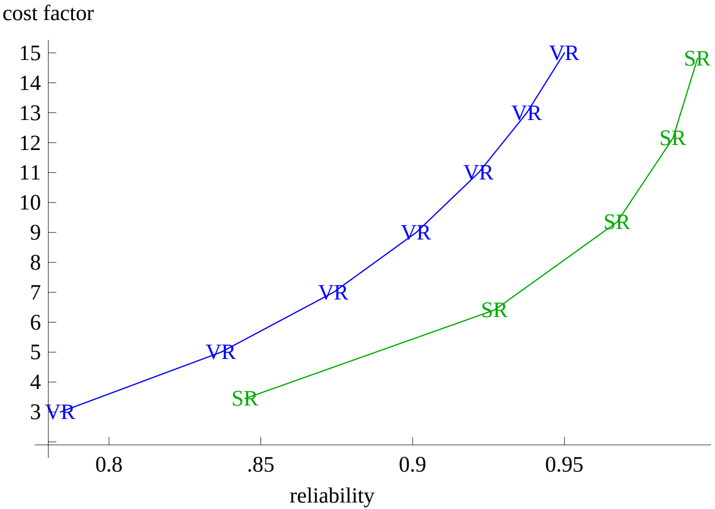
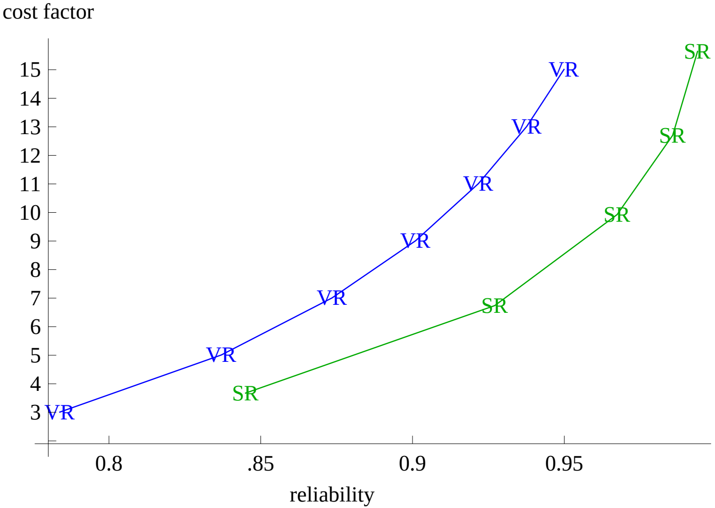
Theoretical results



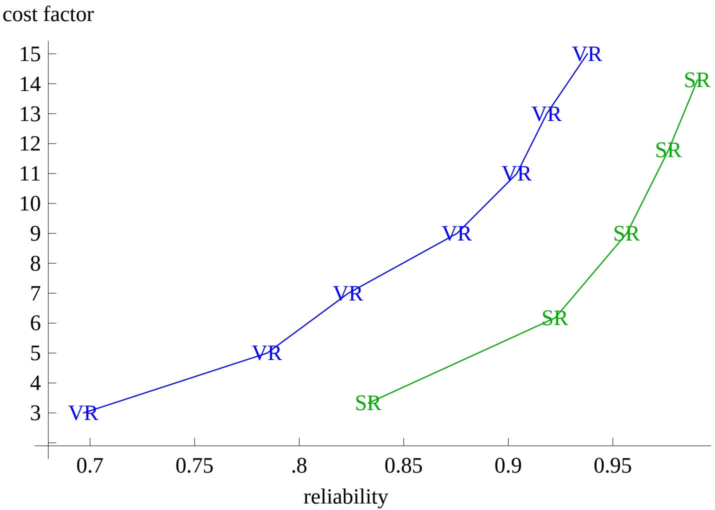
Simulation analysis confirms theoretical predictions

Simulated 1,000,000 task executions on 10,000 nodes using the XDEVS simulator [Edwards 2010]

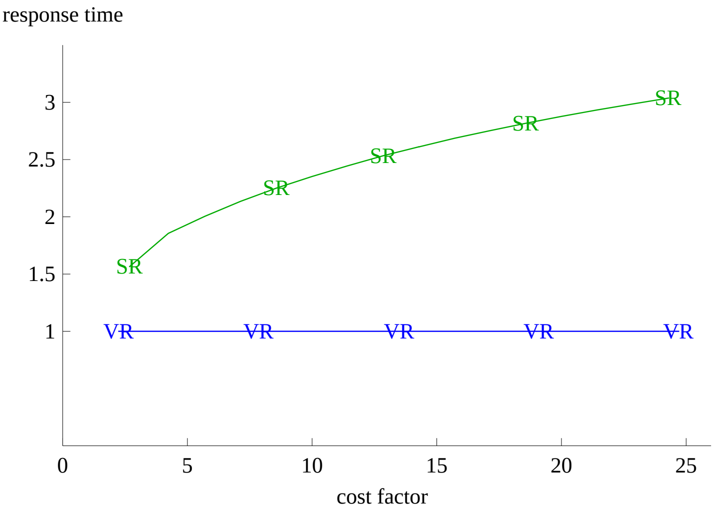


Empirical analysis confirms theoretical predictions

Deployed a SAT solver using BOINC [Anderson 2004] on PlanetLab [Peterson et al. 2003]



Response time cost



Iterating increases individual task response time

Related work

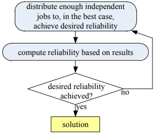
other redundancy techniques

- self-configuring optimistic programming [Bondavalli et al. 2002]
- credibility-based fault tolerance [Sarmenta 2002]
- checkpointing [Priya et al. 2007]

complementary

- primary backup [Budhiraja et al. 1993]
- active replication [Schneider 1990]
- developer-defined fault detection [Hwang and Kesselman 2003]

Contributions



smart redundancy: using resources optimally to boost reliability

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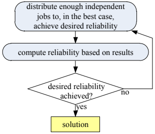

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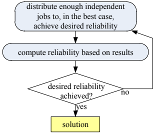

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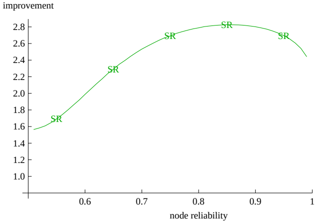

formally and empirically verified improvement

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David P. Anderson. BOINC: A system for public-resource computing and storage. In *Proceedings of the 5th IEEE/ACM International Workshop on Grid Computing (GRID04)*, pages 4–10, Pittsburgh, PA, USA, 2004. ISBN 0-7695-2256-4. doi: http://dx.doi.org/10.1109/GRID.2004.14.

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