A class of precomputation-based distance-bounding protocols

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(joint work with Sjouke Mauw and Rolando Trujillo-Rasua,
to appear at Euro S&P 2016)

Nancy, France. March 16, 2016

Relay attack: how to beat a grand master

White

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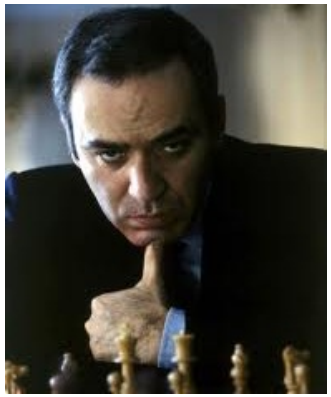

Relay attack: how to beat a grand master

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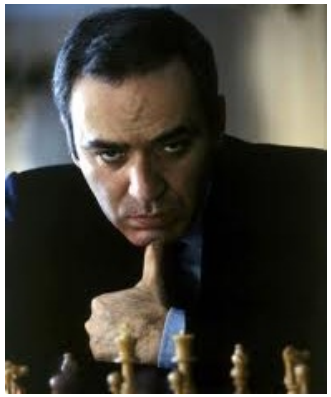

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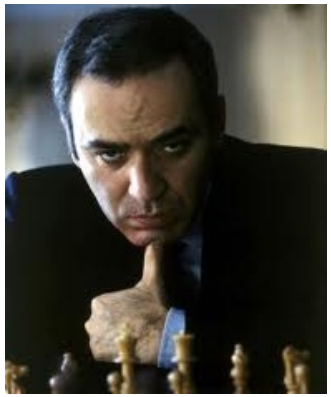

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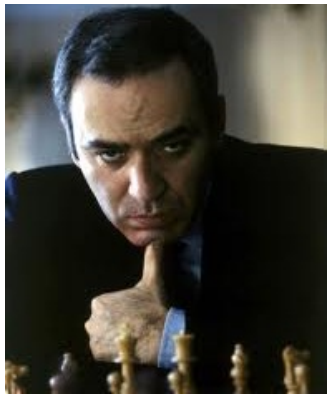

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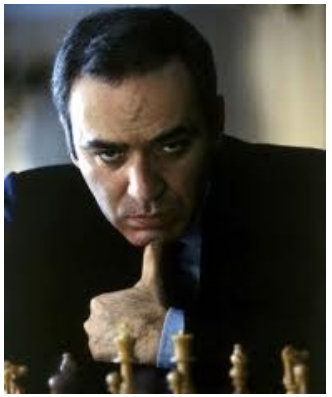

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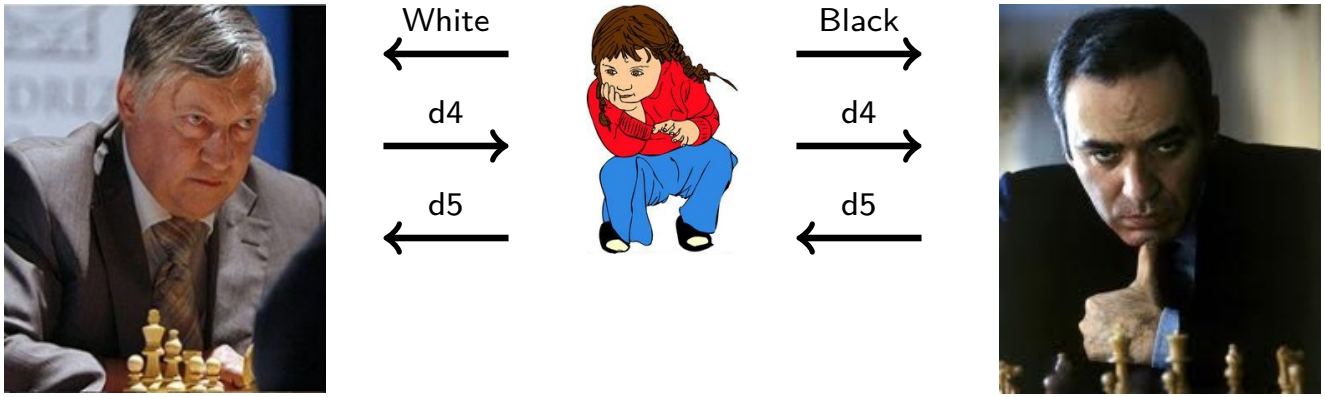

Definition (Relay attack)

A relay attack is a man-in-the-middle attack where the adversary manipulates the communication by only relaying the verbatim messages between reader and the tag.

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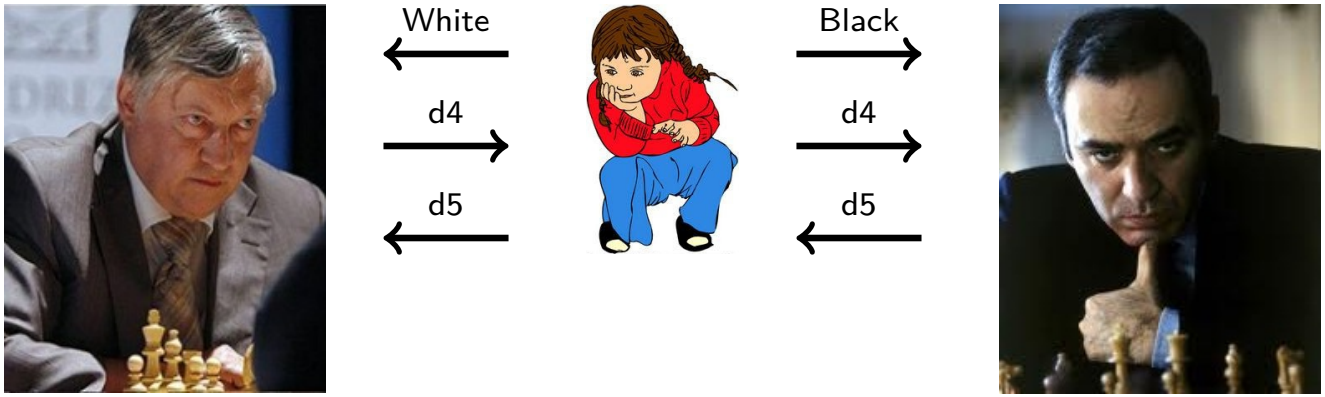

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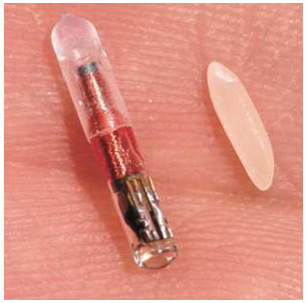
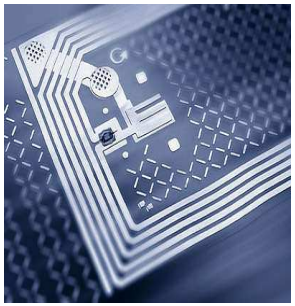
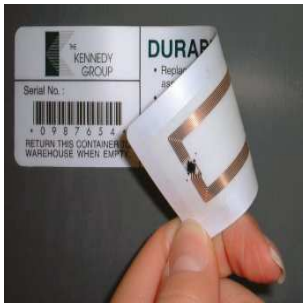
Solution: distance bounding protocols

Definition (Distance Bounding)

A distance bounding protocol is an authentication protocol that in addition checks the distance between tag and reader. The computed distance is an upper-bound on their actual distance.

Radio Frequency Identification - RFID



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- Line-of-sight is not necessary.
- Messages are broadcast.
- Limited resources (memory, processor speed, energy, interaction time).

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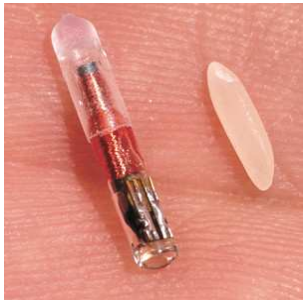
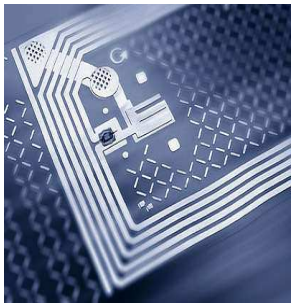

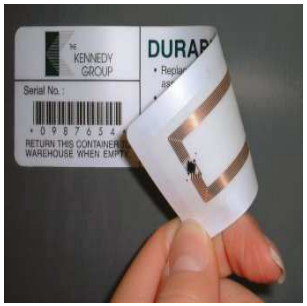

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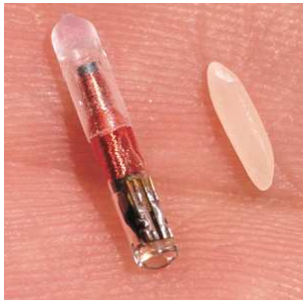
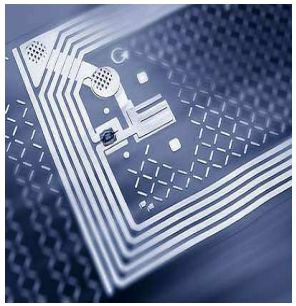

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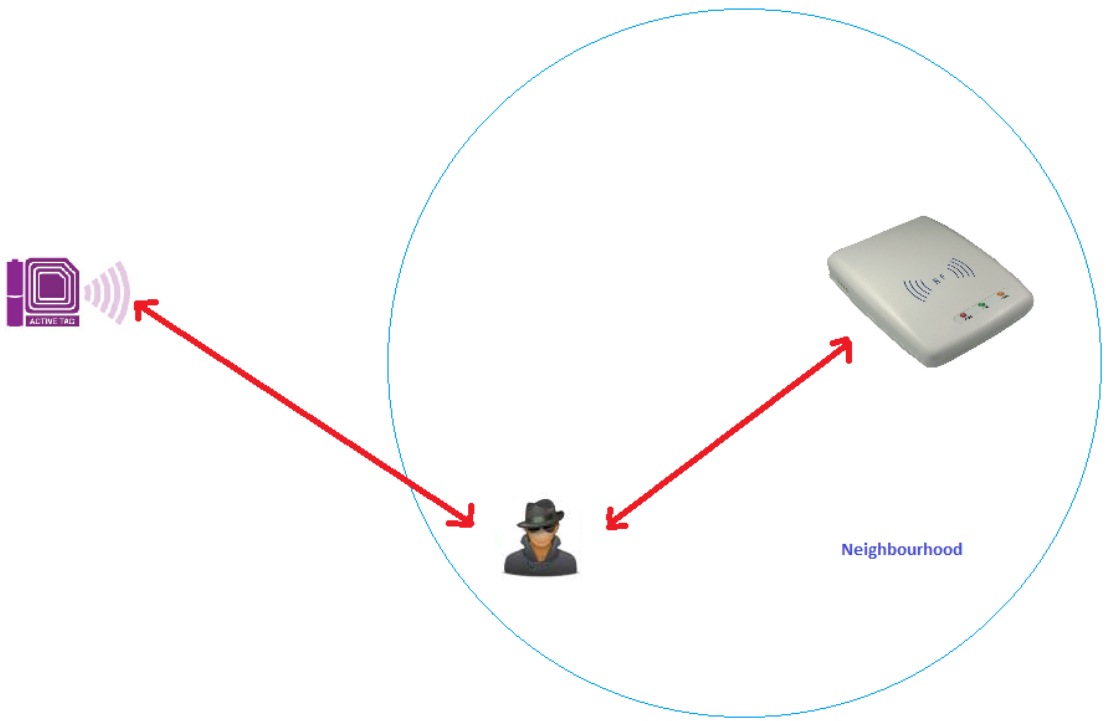
Mafia-fraud attacks



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- distance fraud
- terrorist fraud
- distance hijacking

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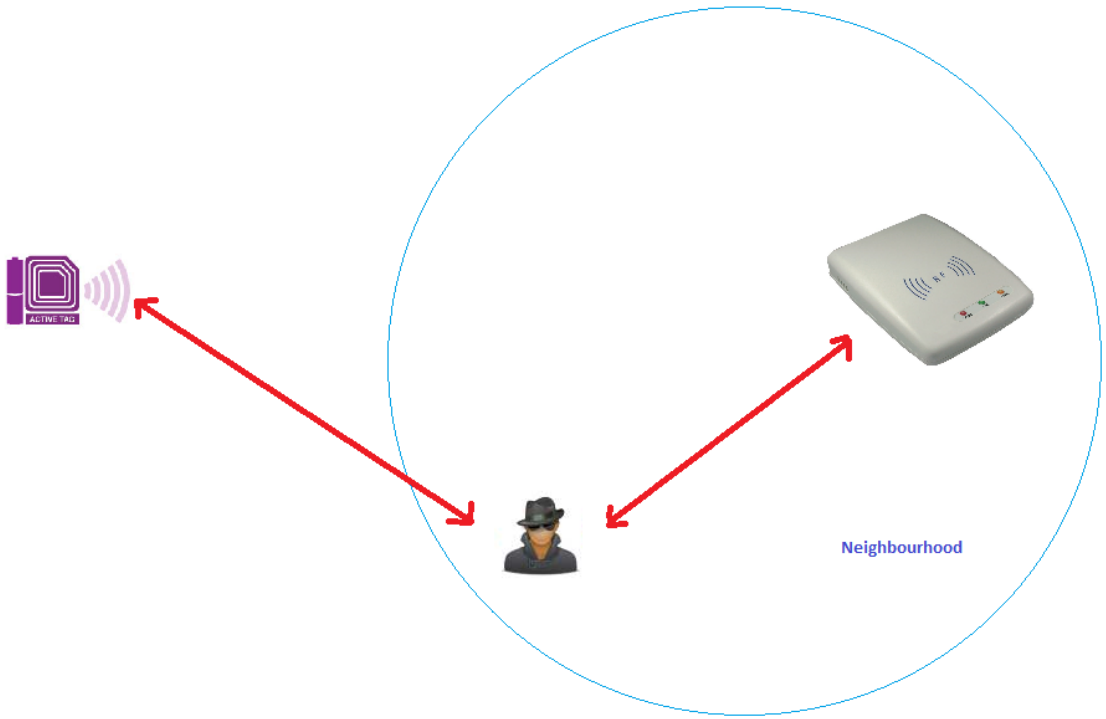

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A few distance bounding protocols

- Brands and Chaum (Fiat-Shamir)
- Brands and Chaum (Schnorr)
- Brands and Chaum (signature)
- Bussard and Bagga
- CRCS
- Hancke and Kuhn
- Hitomi
- KA2
- Kuhn, Luecken, Tippenhauer
- MAD
- Meadows et al. for $F(\cdots) = \langle NV, NP \oplus P \rangle$
- Munilla and Peinado
- Noise resilient MAD
- Poulidor
- Reid et al.
- Swiss-Knife
- Tree
- WSBC+DB
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Many of them have been broken

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Some common principles

- Are composed by two phases:
  - Slow phase: generation of random values, exchange of parameters, preparation of data structures.
  - Fast phase: 1-bit messages, tag performs at most lookup/and/xor/...; repeat this n times.
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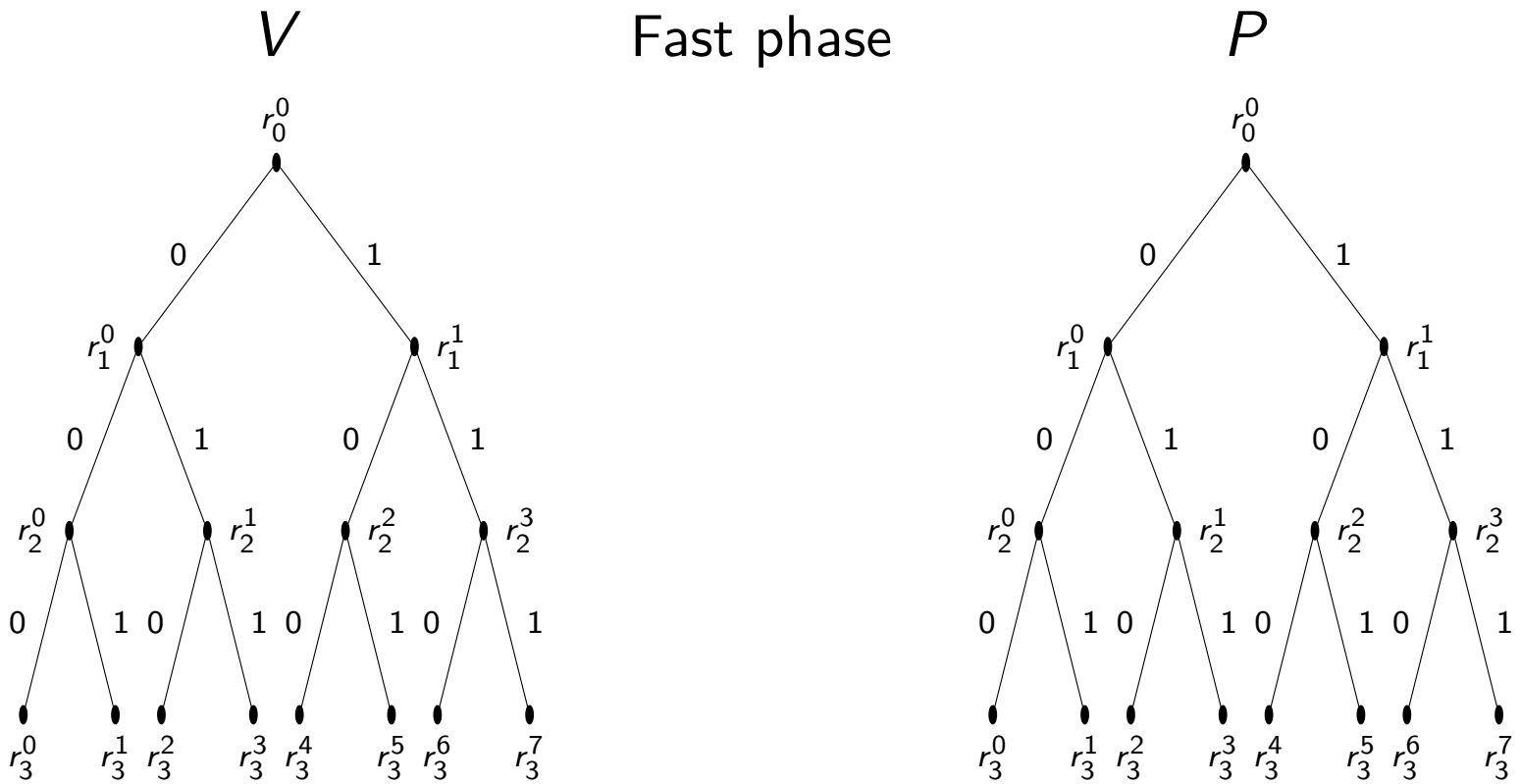

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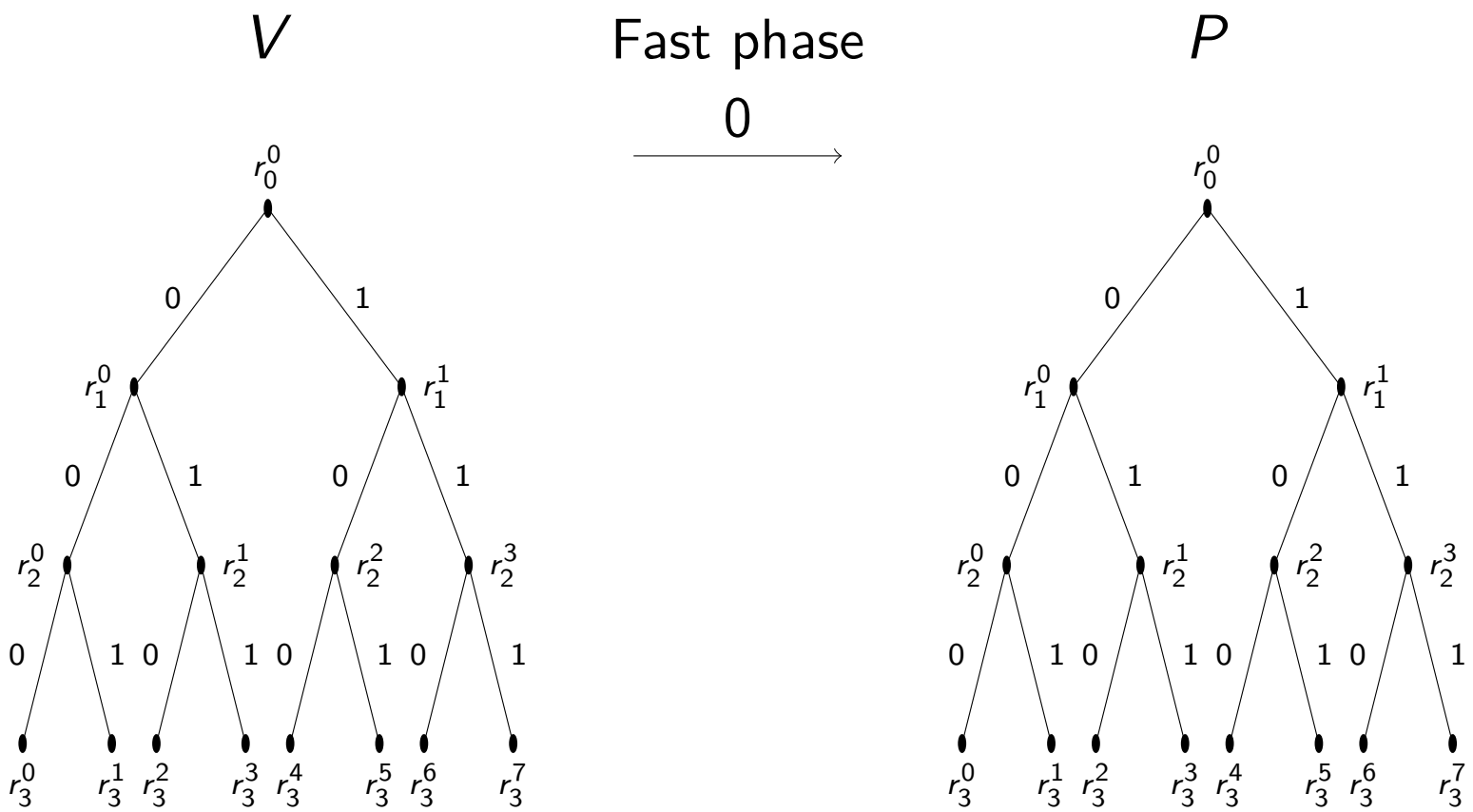

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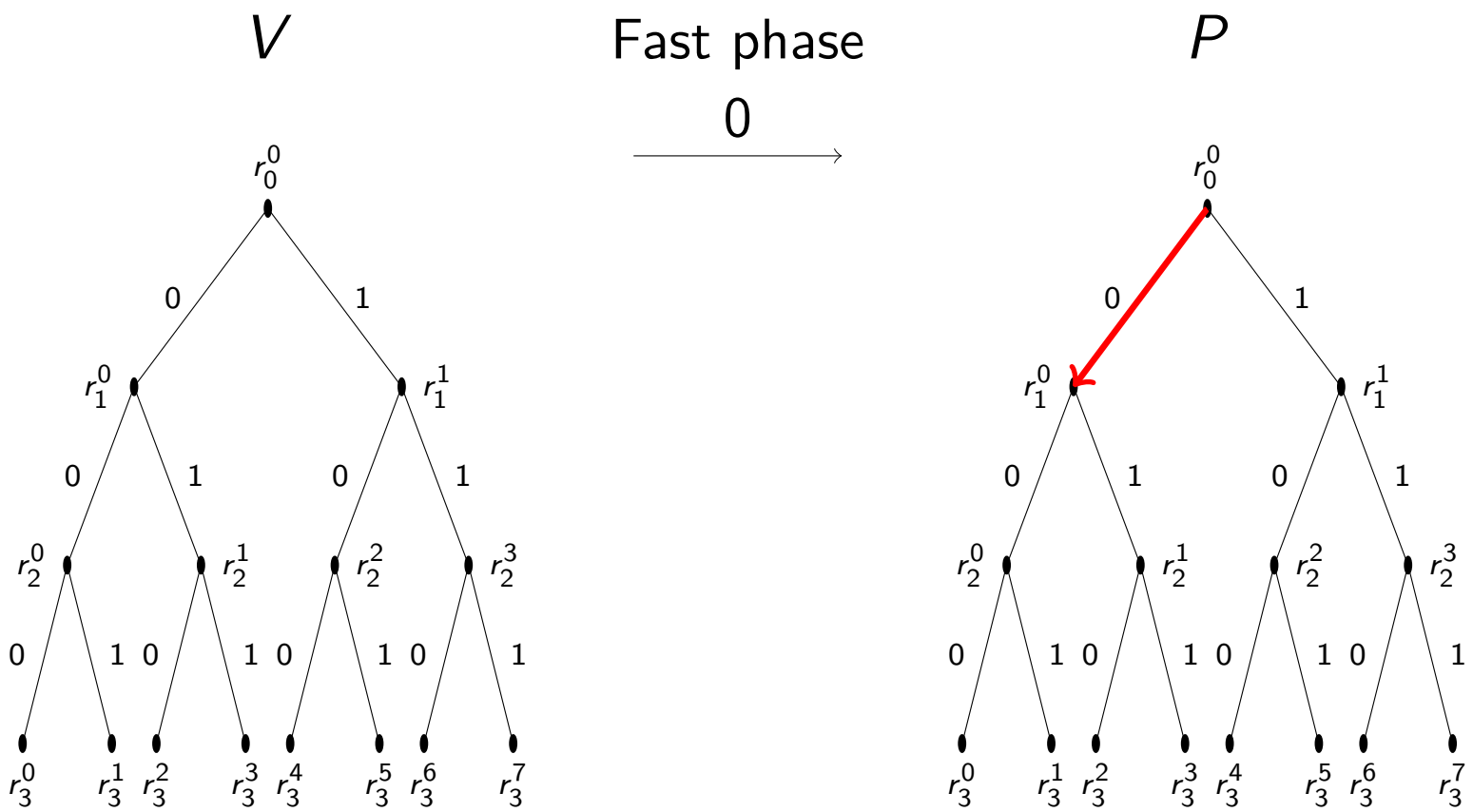

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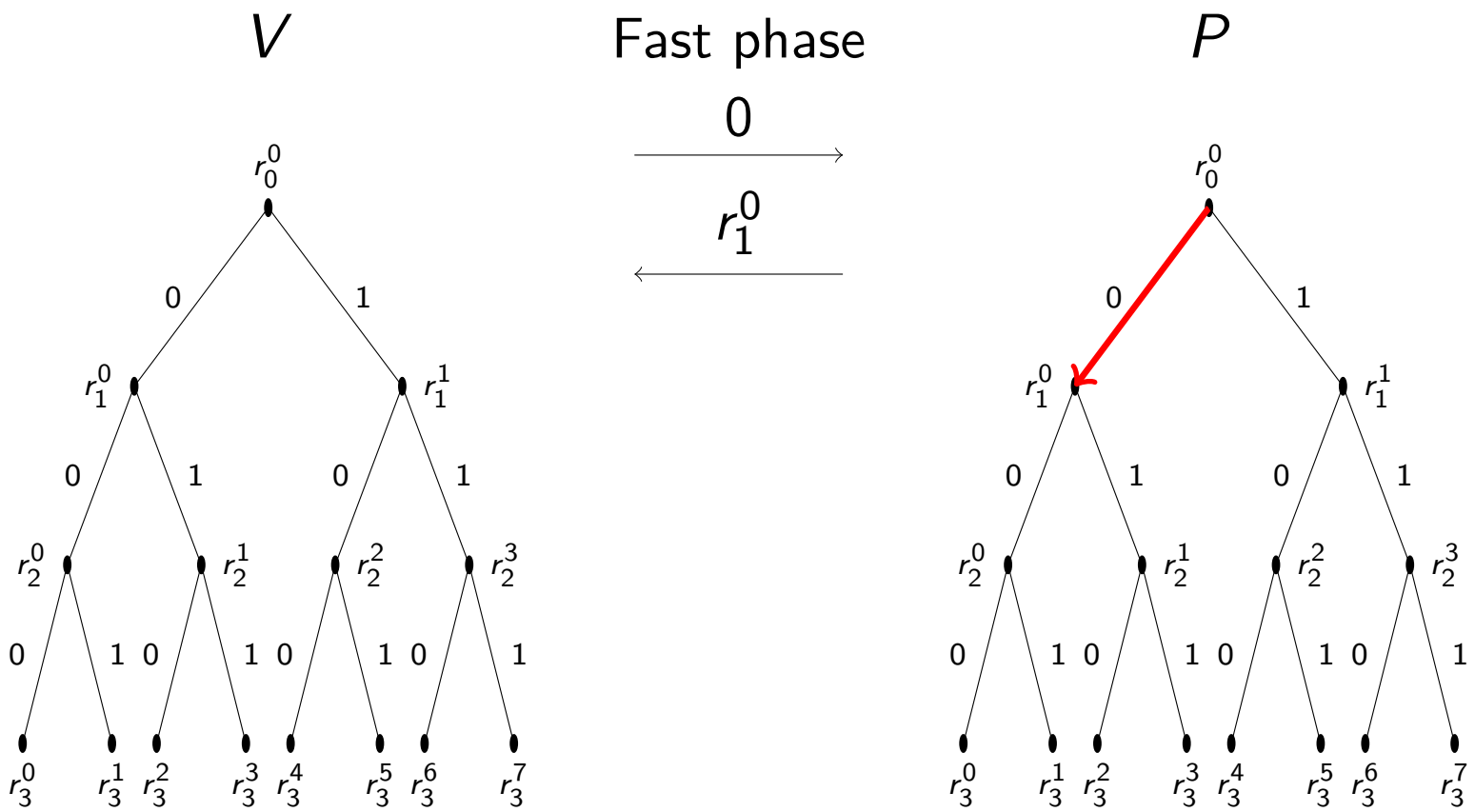

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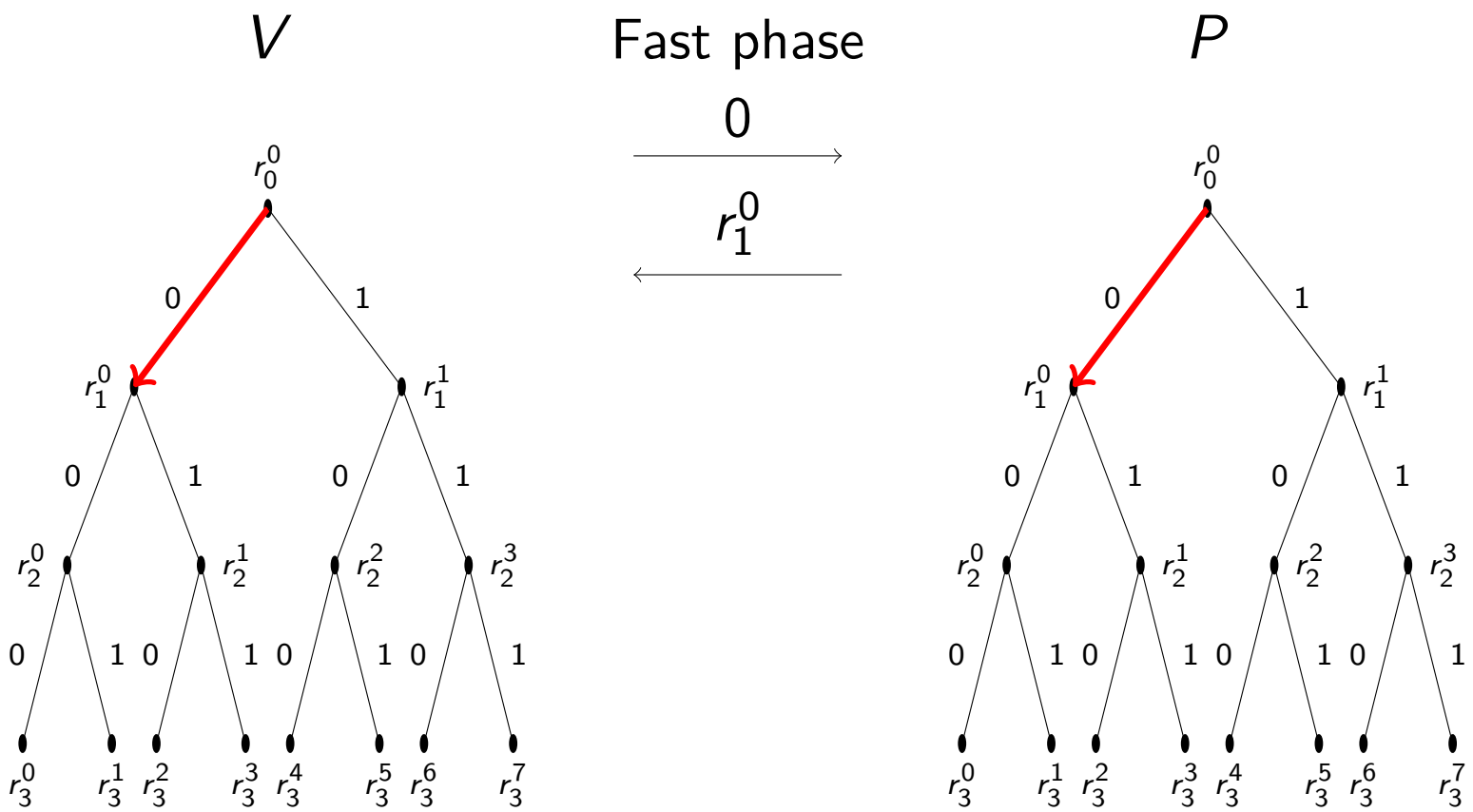

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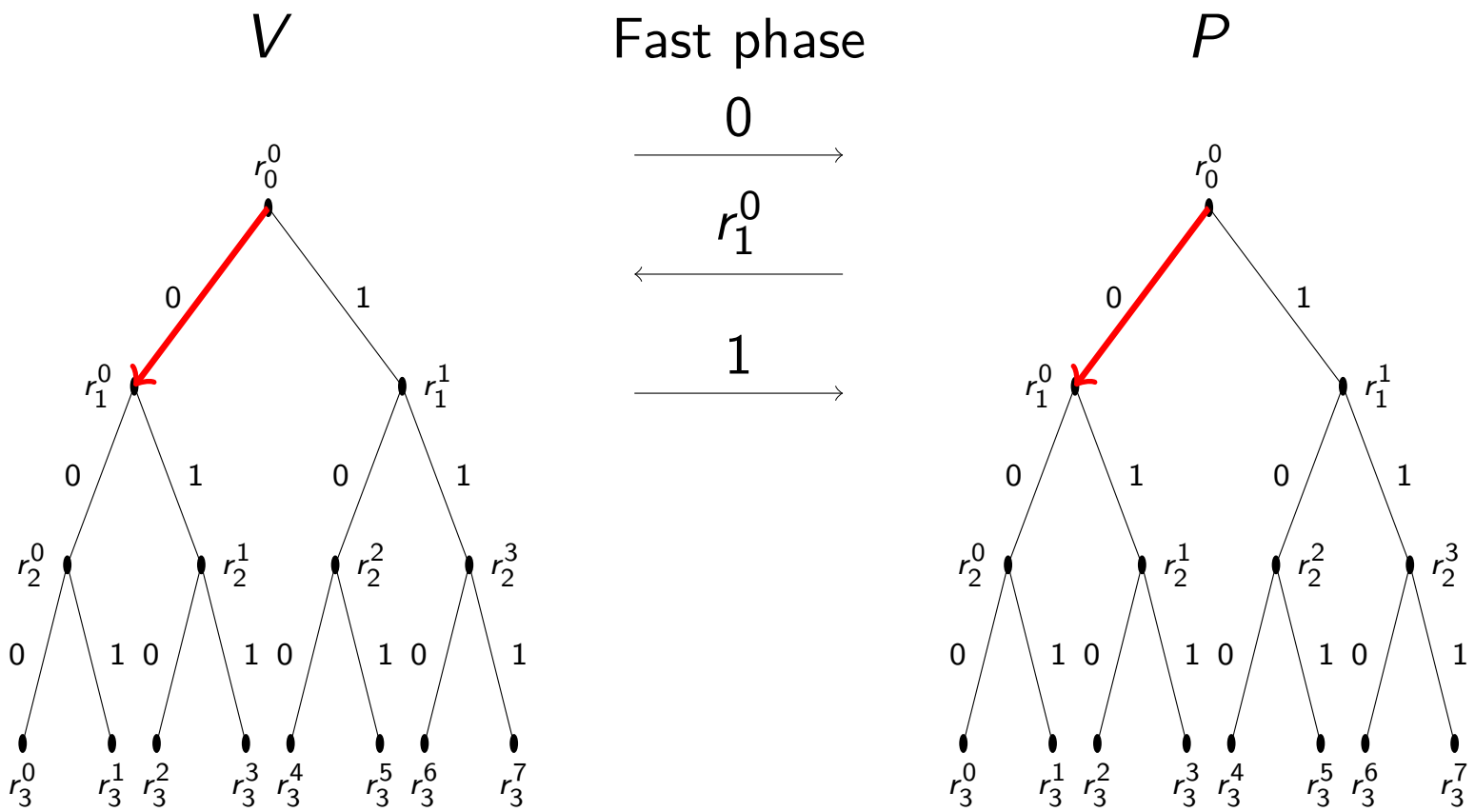

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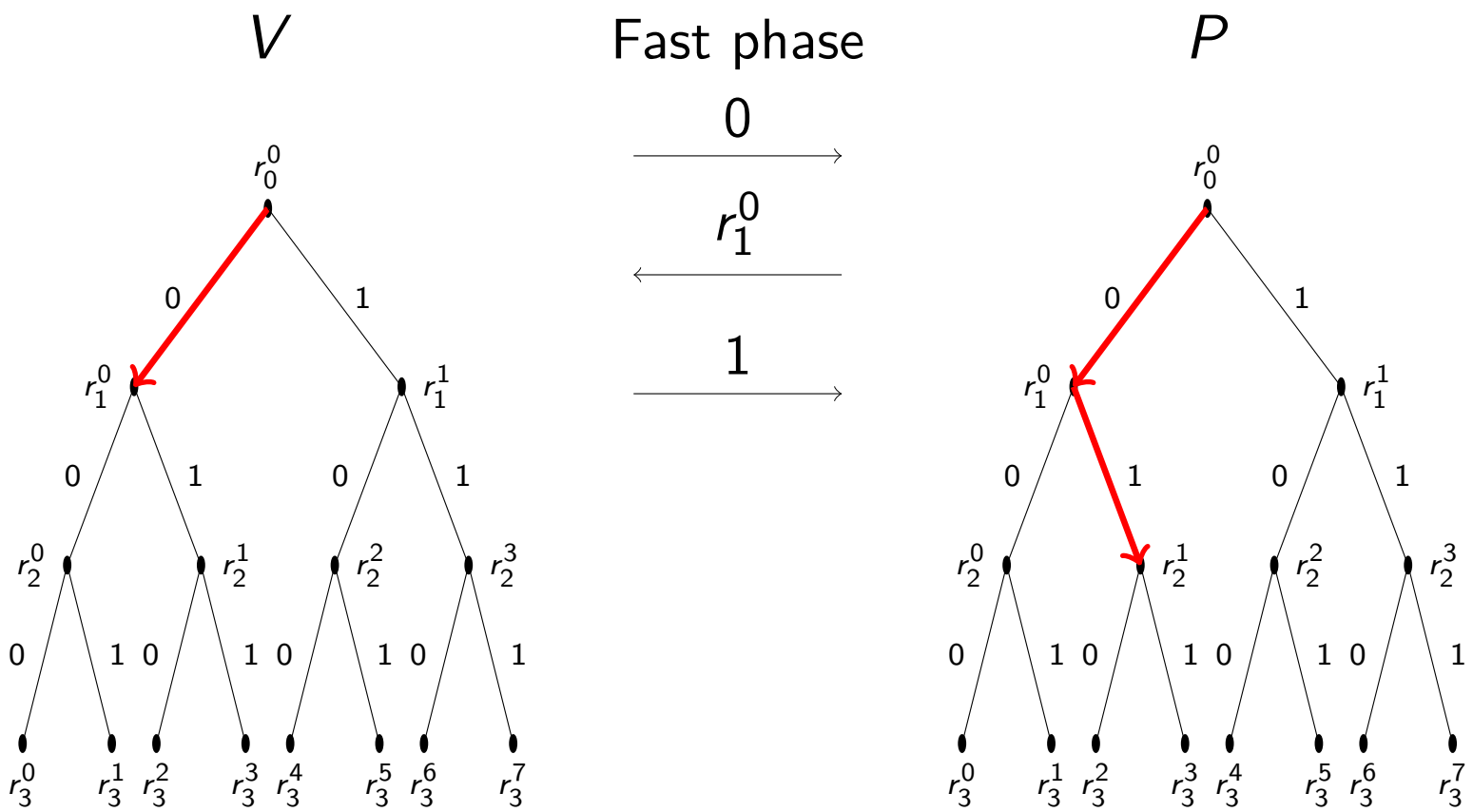

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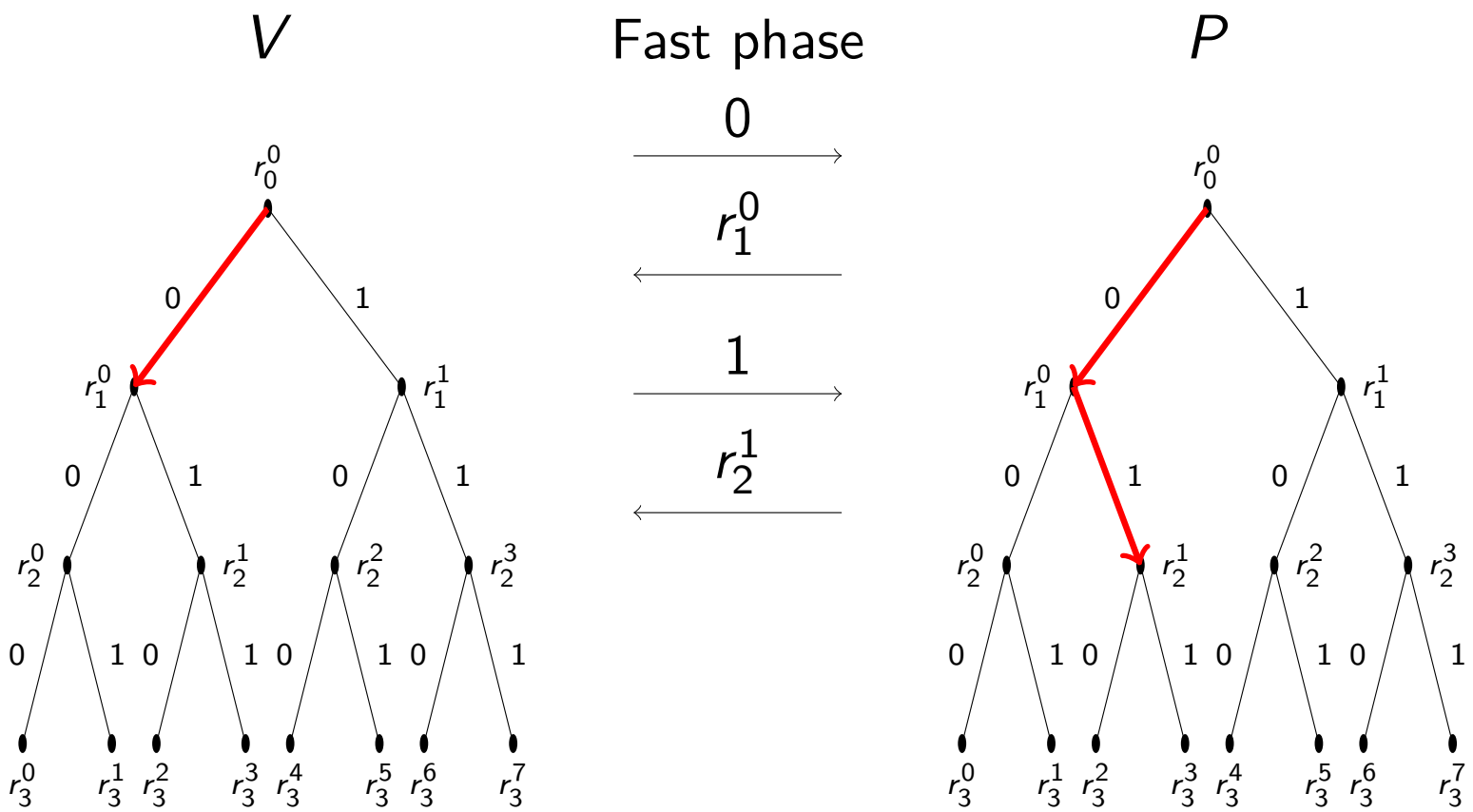

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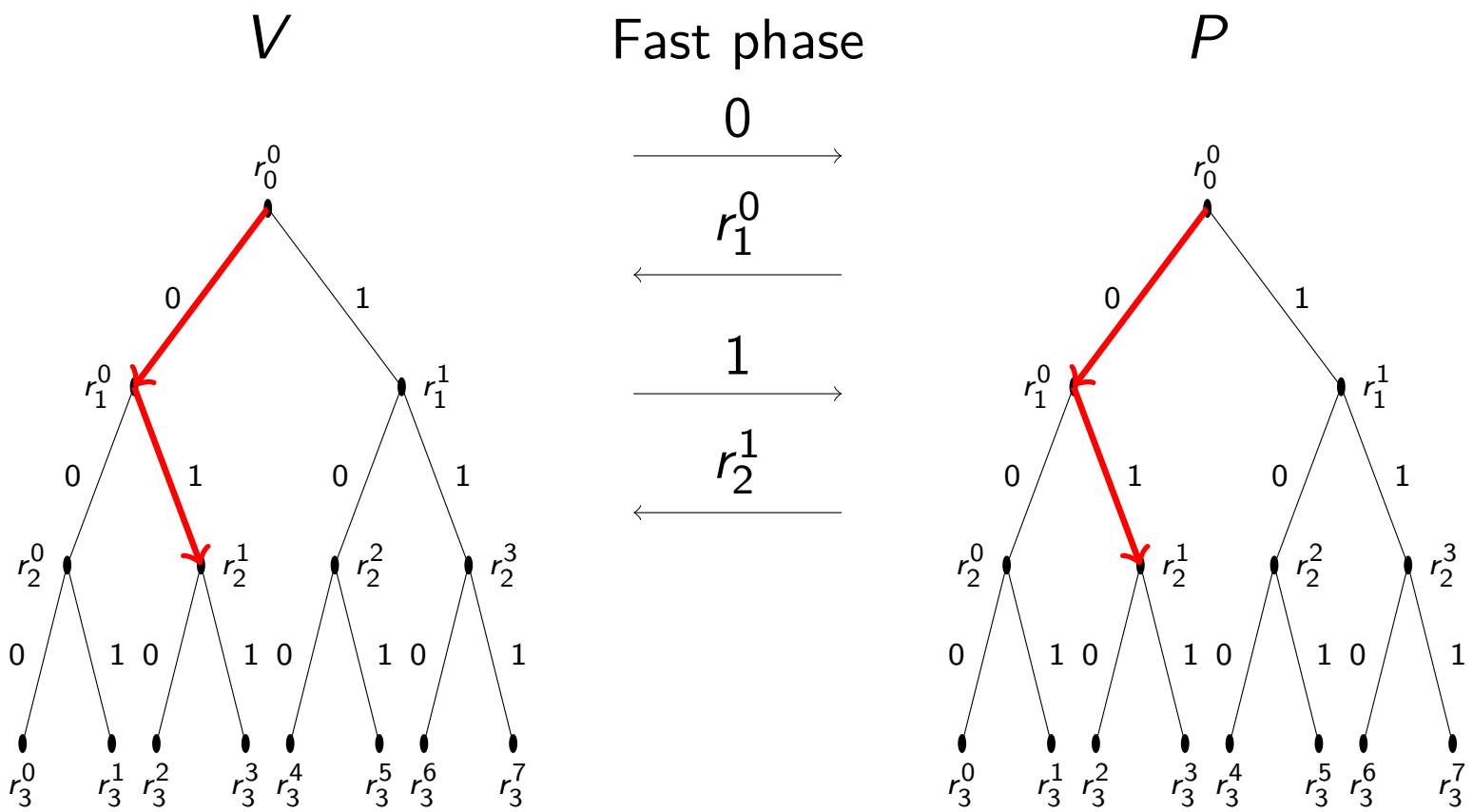

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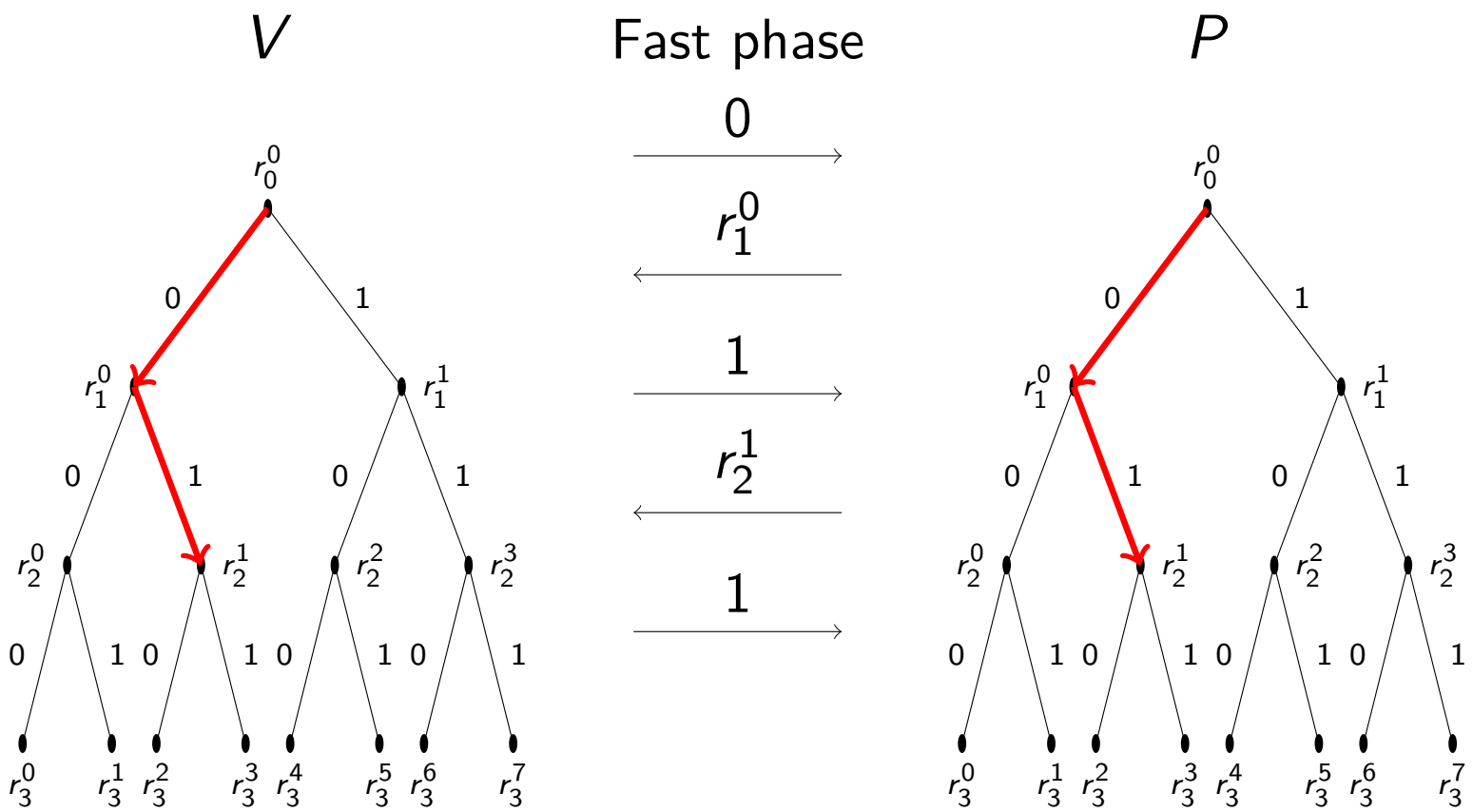

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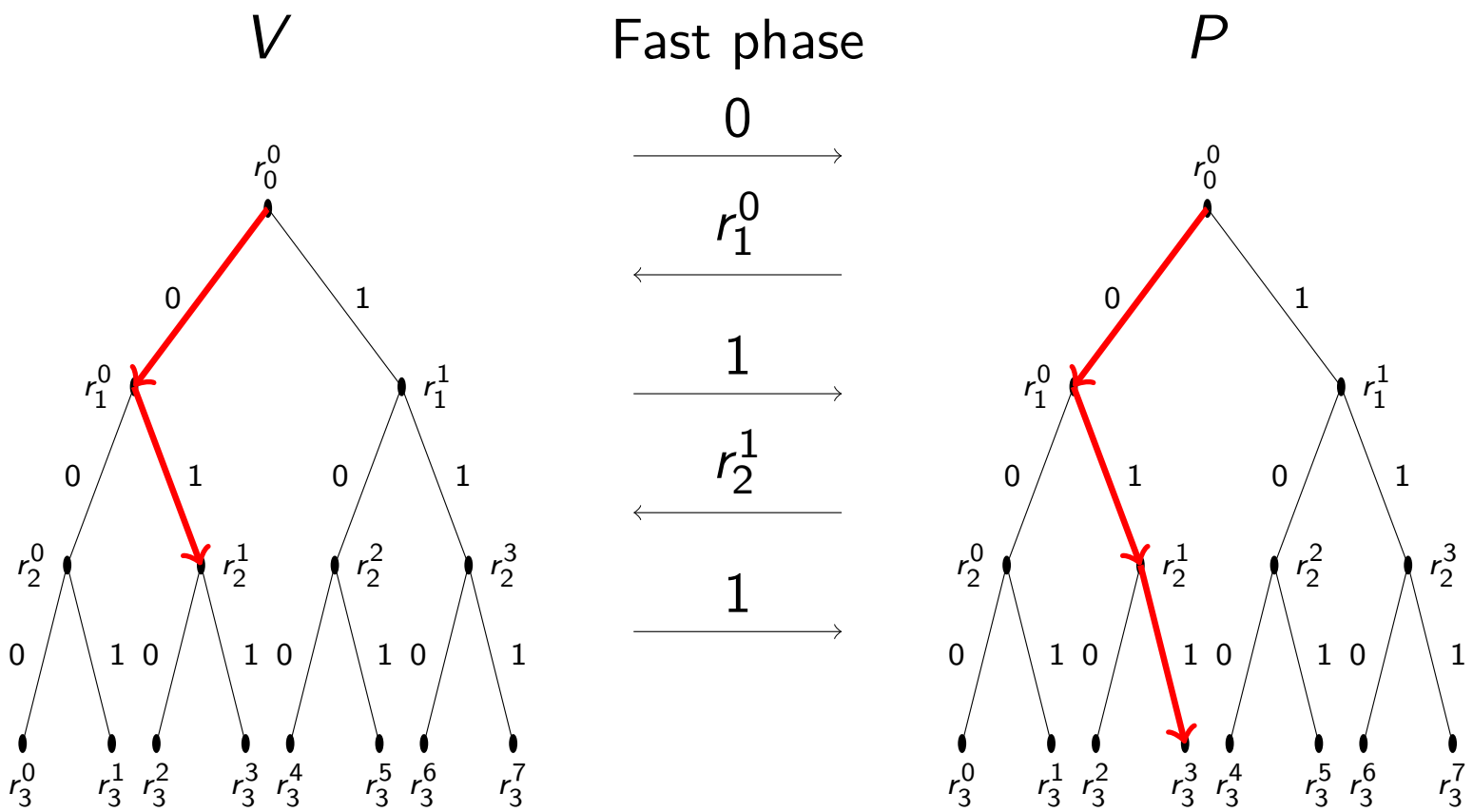

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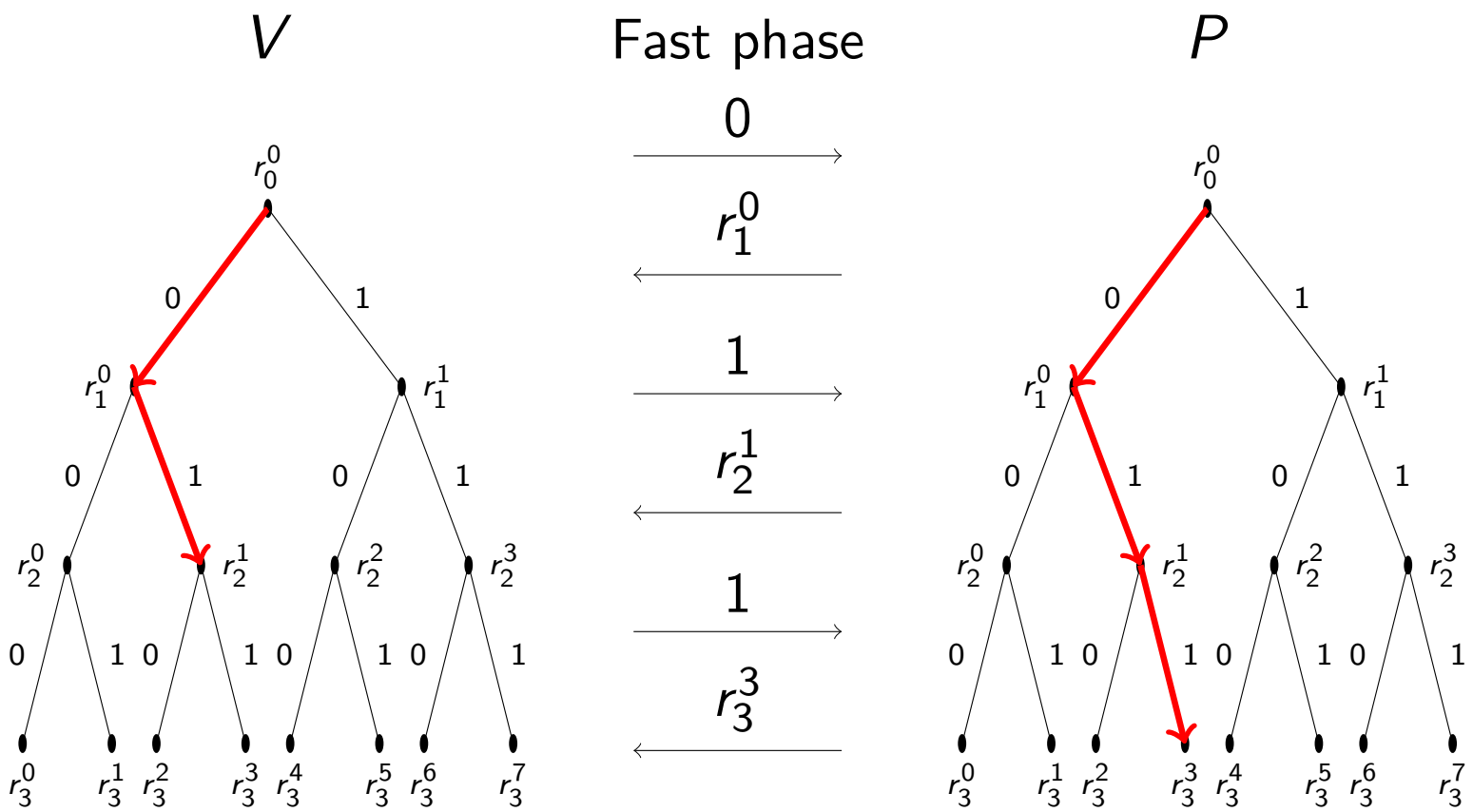

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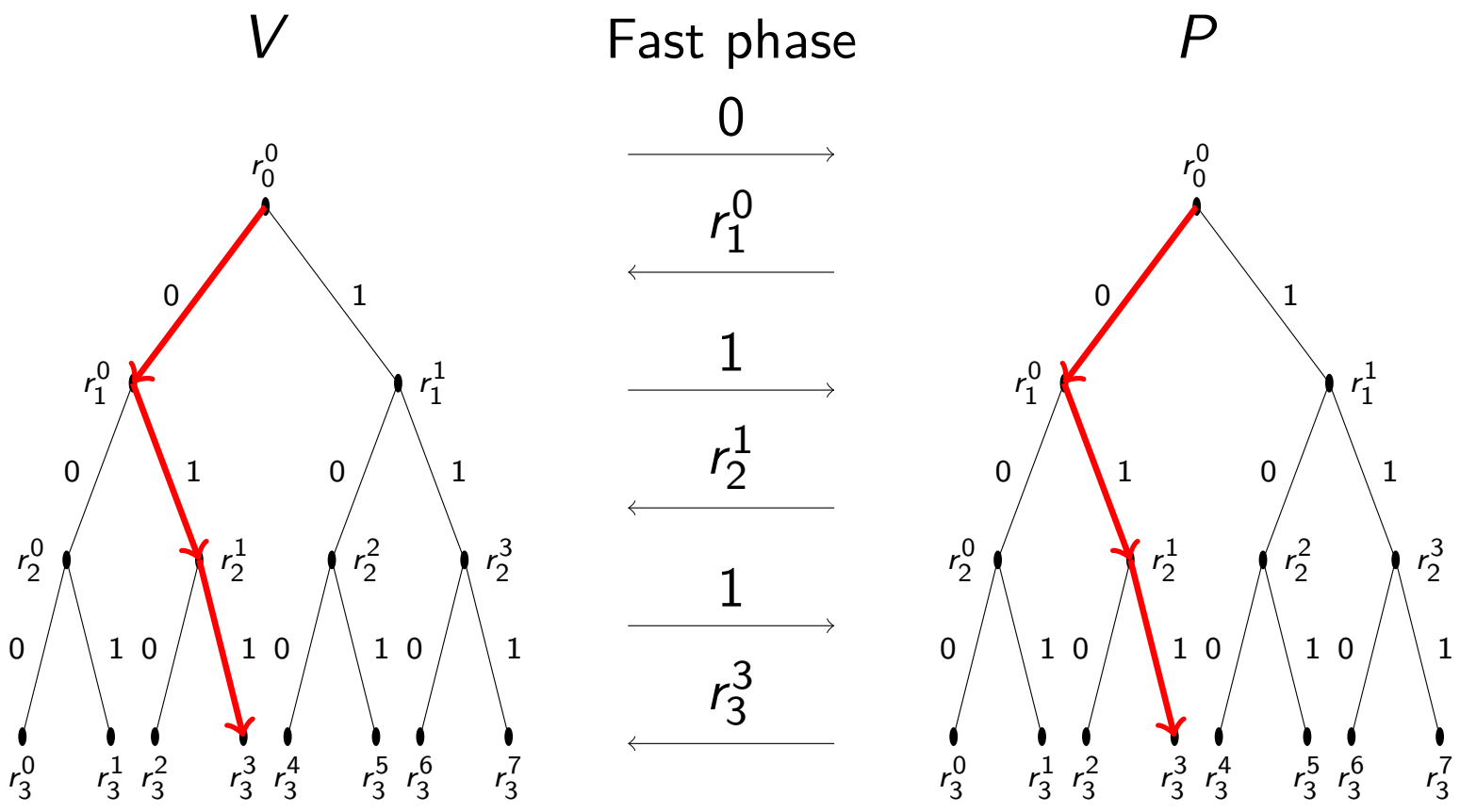

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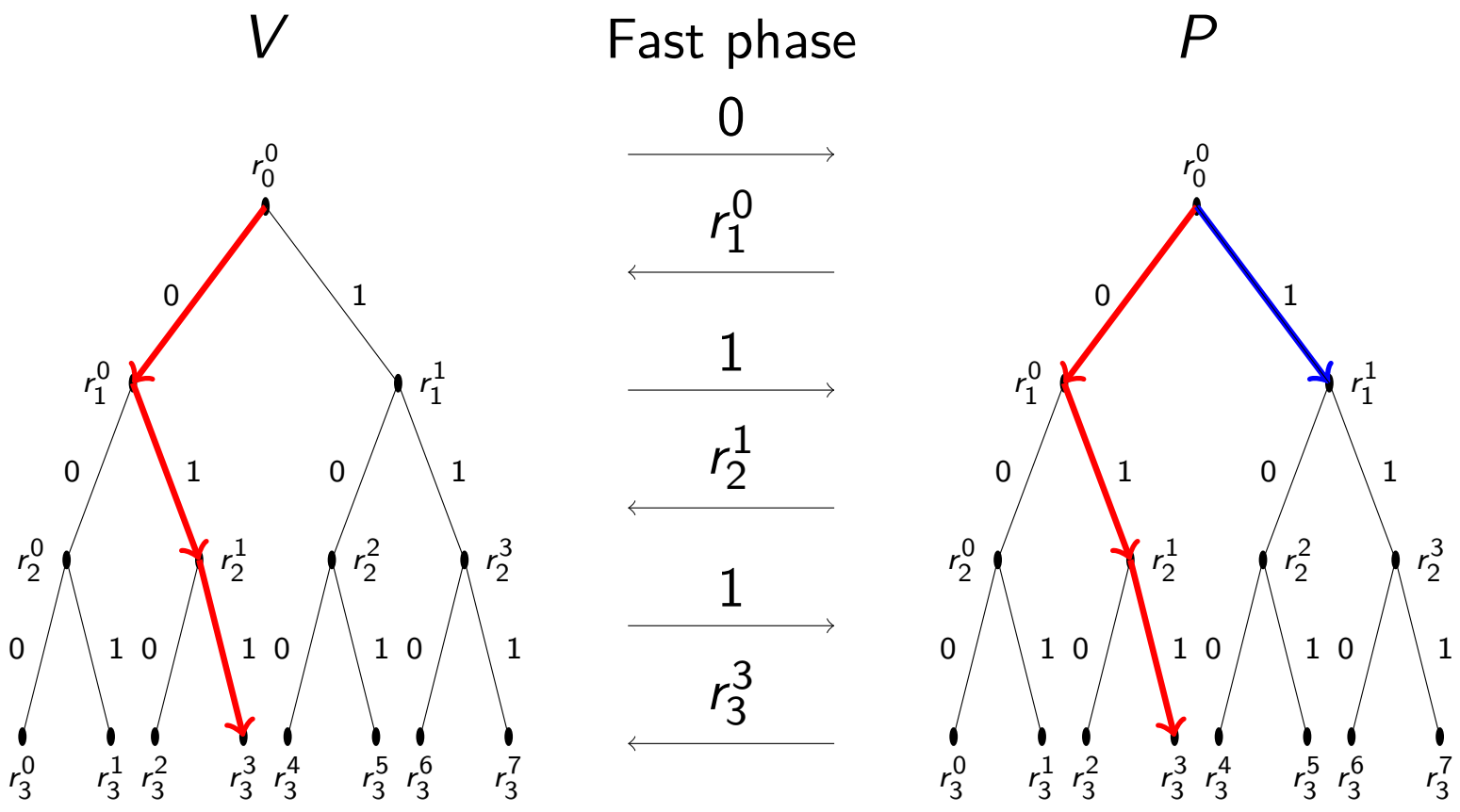

Two well-known lookup-based protocols

	Mafia Fraud	Memory usage
HK protocol	$\left(\frac{3}{4}\right)^n$	$O(n)$
AT protocol	$\frac{1}{2^n}(1+\frac{n}{2})$	$O(2^n)$

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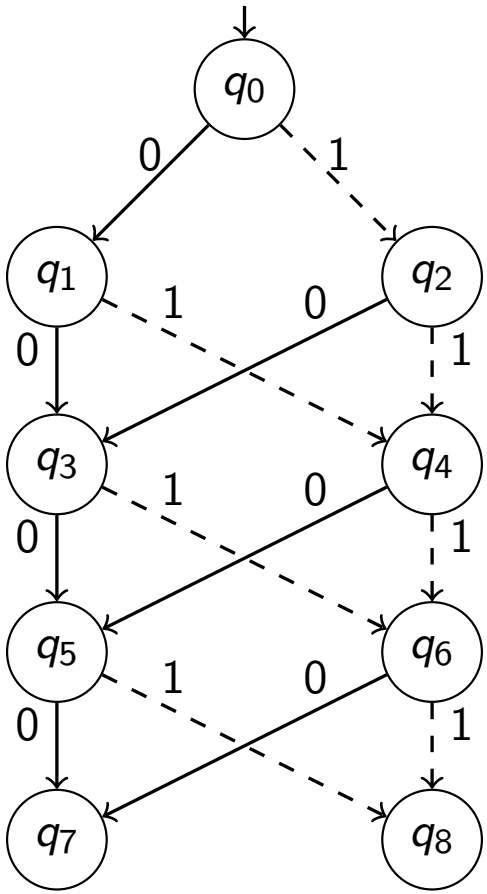
Questions

1. Can we model this class of lookup-based protocols and perform a generic analysis for its elements?
2. Does it exist a lookup-based protocol better than AT?
3. Do we need an exponential memory to achieve $\frac{1}{2^n}(1 + \frac{n}{2})$?

The model: Finite Automata



An example of HK protocol with 4 rounds.

Properties: lower bound

Theorem

The probability value $\frac{1}{2^n}\left(1+\frac{n}{2}\right)$ *is a tight lower bound on the resistance to mafia fraud of lookup-based distance-bounding protocols with n rounds.*

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Properties: generic calculation of security

We introduce the uniformity number $u \in \{1, \ldots, n\}$ of a protocol. The higher u, the harder it is for the attacker to predict the state of the protocol.

Theorem

Let P be a lookup-based distance-bounding protocol with uniformity number u for $n > 0$ rounds. Then the success probability of a mafia-fraud attack is R_n, where $R_0 = 1$ and

$$R_i = \frac{1}{2^i} + \sum_{j=0}^{i-1} \frac{R_{i-j-1}}{2^{j+\min(u,j+1)+1}},$$

This indeed instantiates to $\left(\frac{3}{4}\right)^n$ for HK and to $\frac{1}{2^n}\left(1 + \frac{n}{2}\right)$ for AT.

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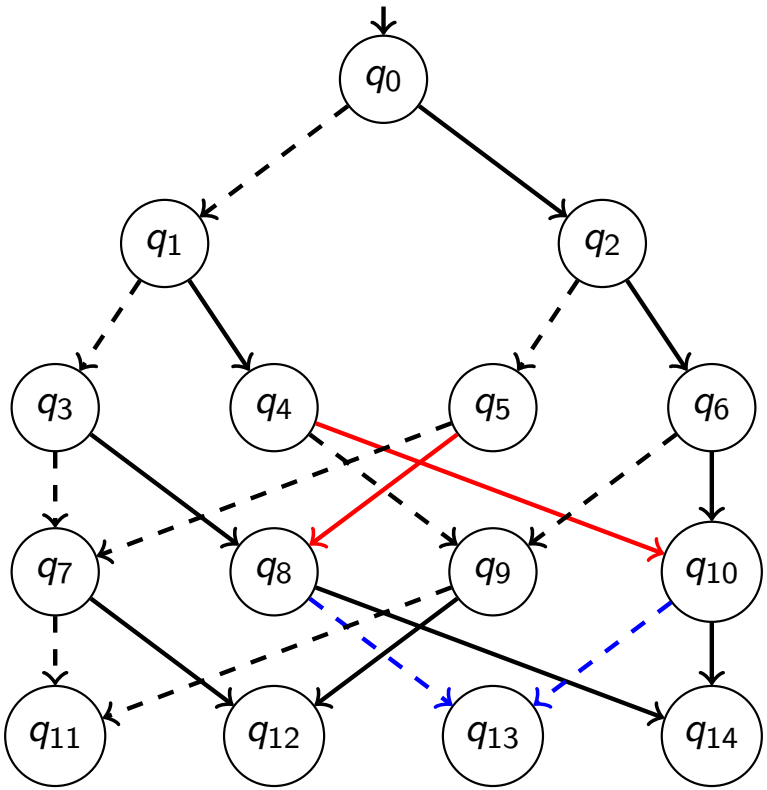
Our proposed protocol

The uniform protocols: an example of a 2-uniform protocol



- Approximates $\frac{1}{2^n}(1 + \frac{n}{2})$
- They required linear space.
- The uniformity value u is pre-defined

Security and memory usage analysis

	Mafia Fraud	Memory usage
HK protocol	$\left(\frac{3}{4}\right)^n$	$O(n)$
u-Uniform	$R_n(u) \xrightarrow[u \to n]{} \frac{1}{2^n}(1+\frac{n}{2})$	$O(2^u \times n)$
AT protocol	$\frac{1}{2^n}(1+\frac{n}{2})$	$O(2^n)$

Conclusions

- Better understanding and generic treatment of lookup-based distance-bounding protocols.
- Fundamental results on security and memory usage.
- Novel family of protocols that approximates optimality with low costs in memory.

- Can we extend our results to a larger class of protocols?
- What is the resistance of lookup-based protocols to distance fraud, terrorist frauds, etc.?
- Can we generalize the various types of fraud into one notion?
- Can we provide a causality-based definition of distance bounding (as opposed to time/space based)?

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Thanks for your attention

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