Rational Choice of Security Measures via Multi-Parameter Attack Trees

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- Even if the losses associated with vulnerability exploits can be estimated, the corresponding probabilities are very difficult to evaluate
- This is especially true for targeted, company-specific attacks, since the required statistics does not exist or is difficult to get

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- Such attacks can be modelled using gradual refinement starting from primary threats and breaking them down to elementary attacks
- As a result, we obtain an *attack tree*

An Attack Tree

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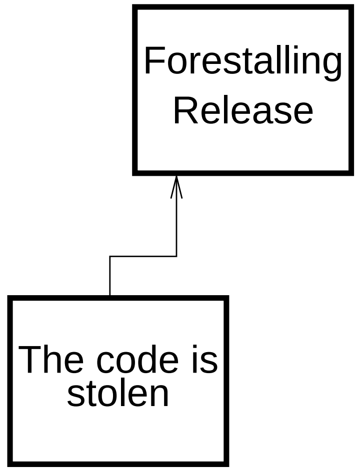

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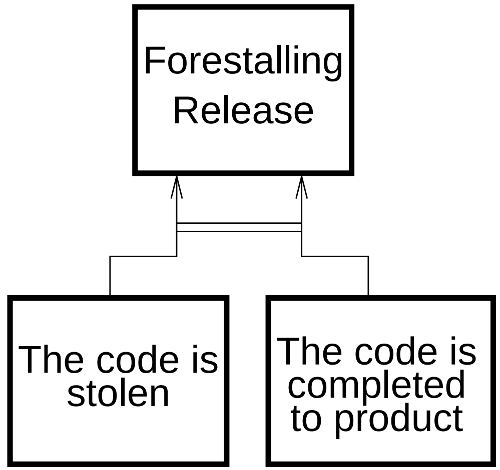

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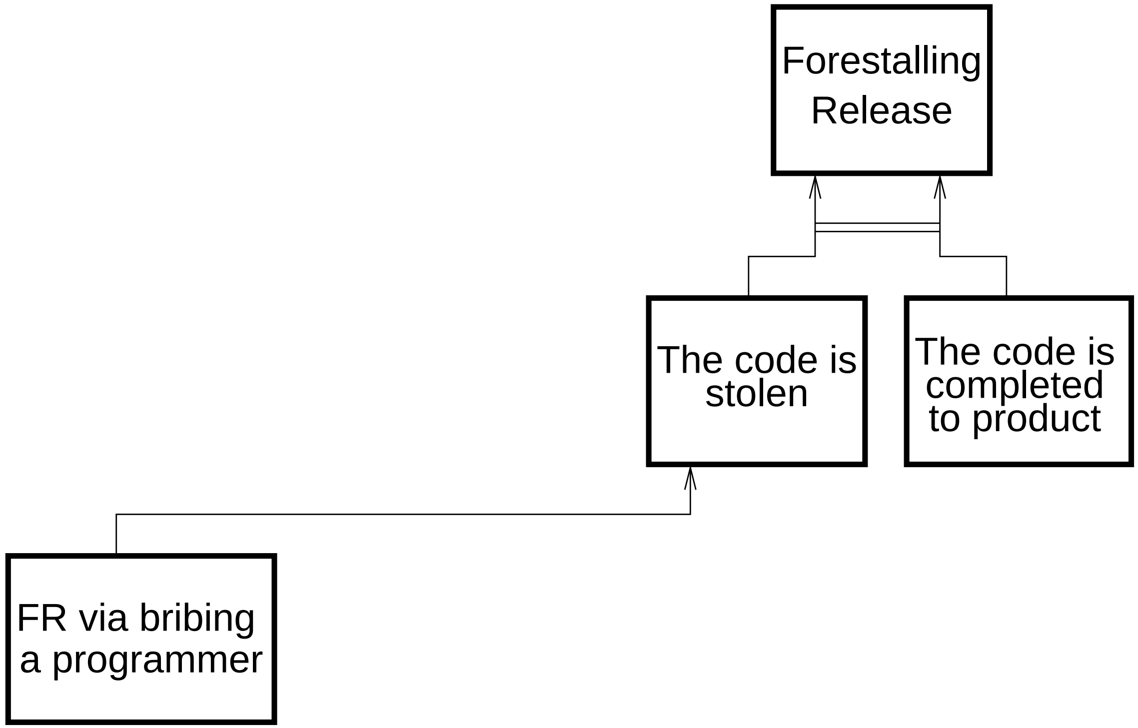

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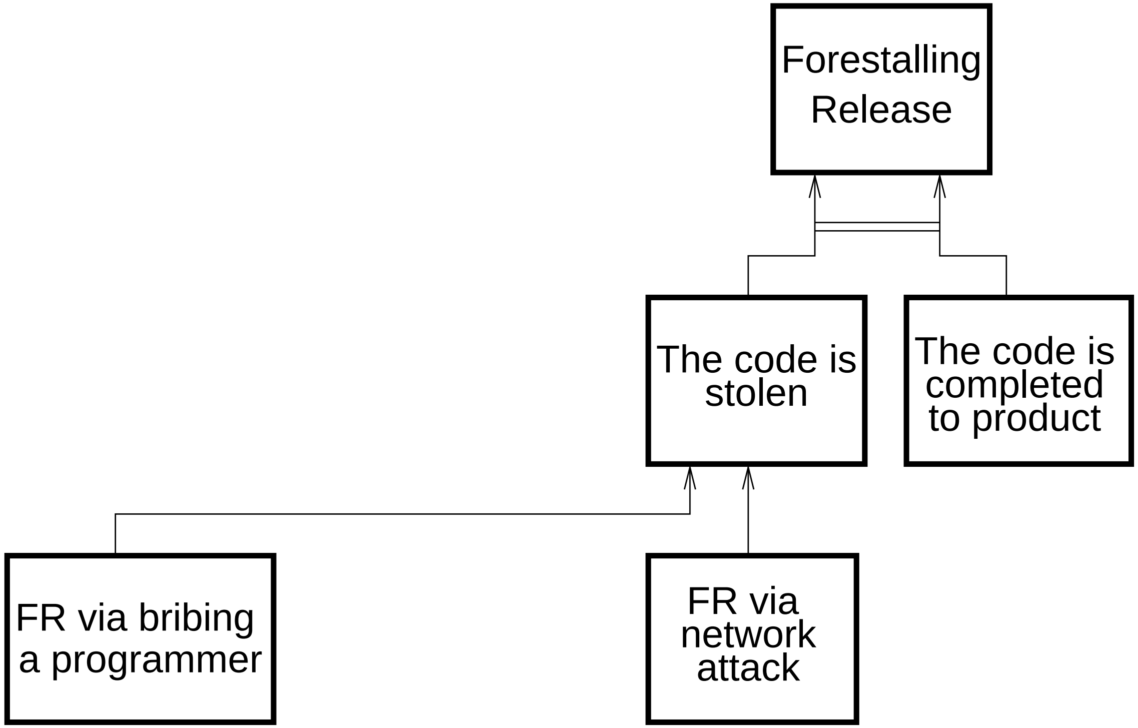

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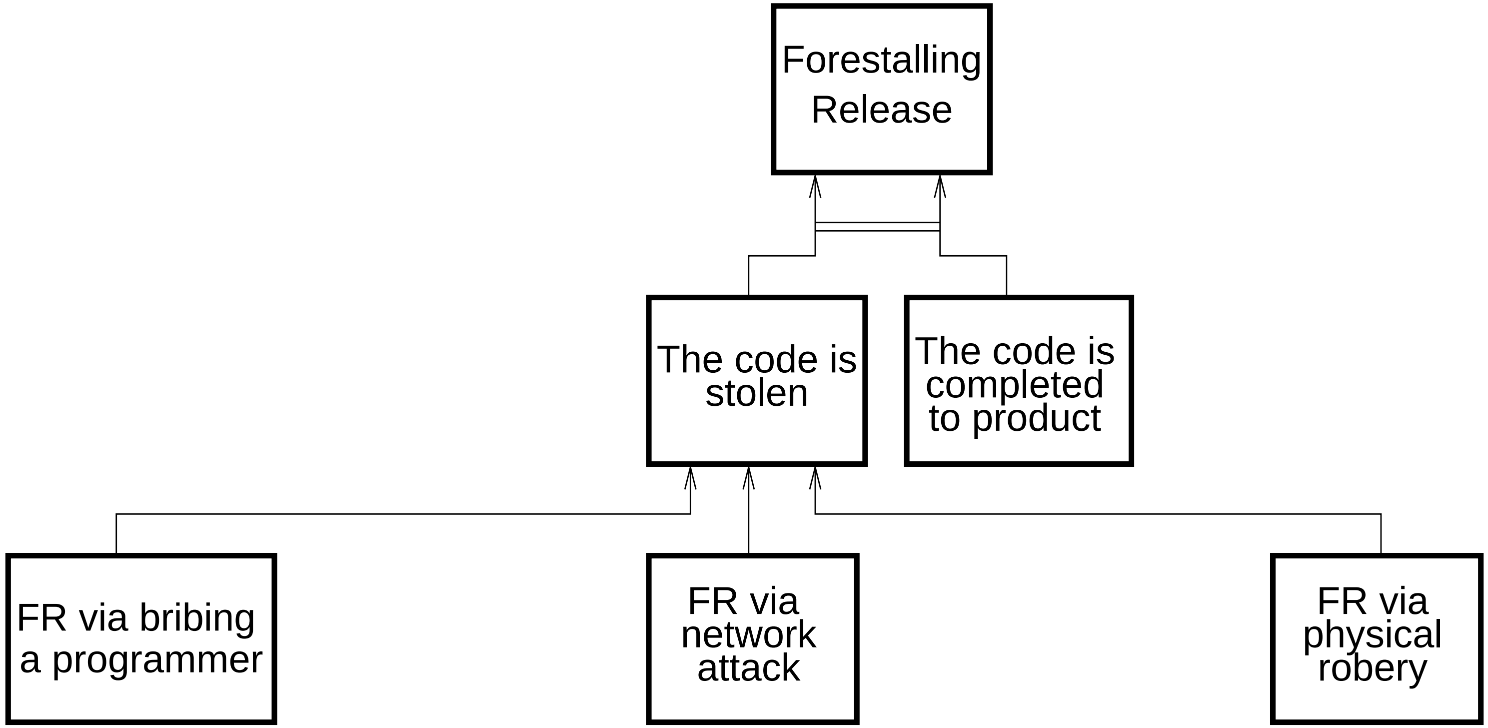

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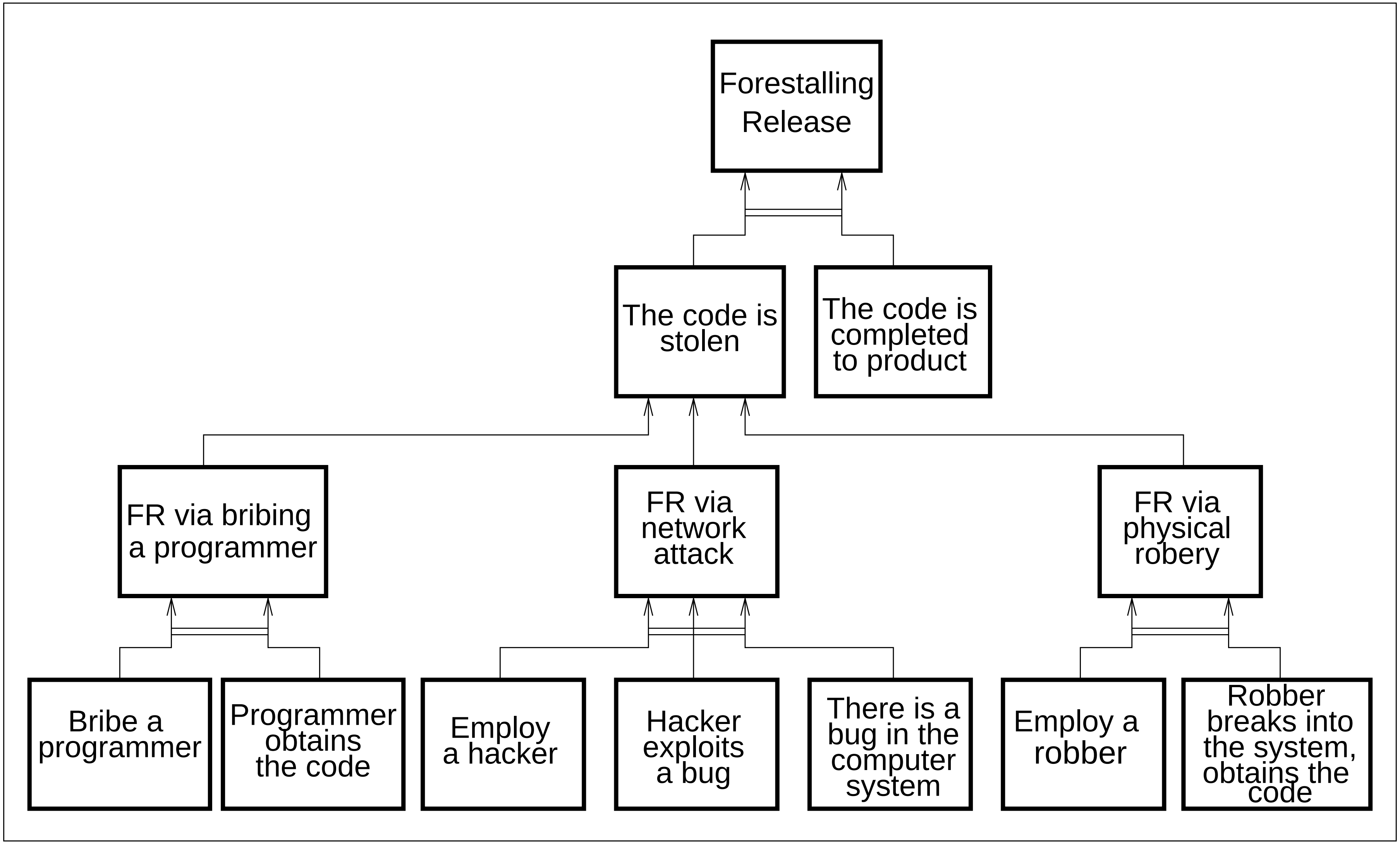

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  - q_-, Penalties$_-$ – the probability of getting caught and penalties (if the attack was unsuccessful)

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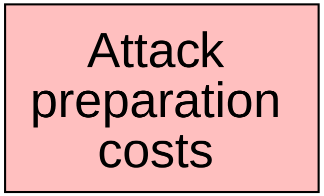

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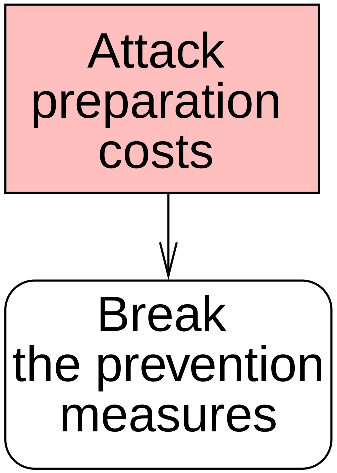

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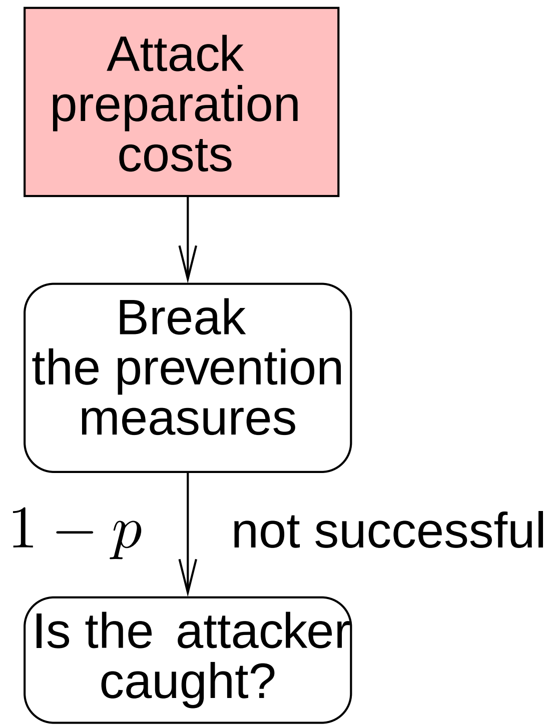

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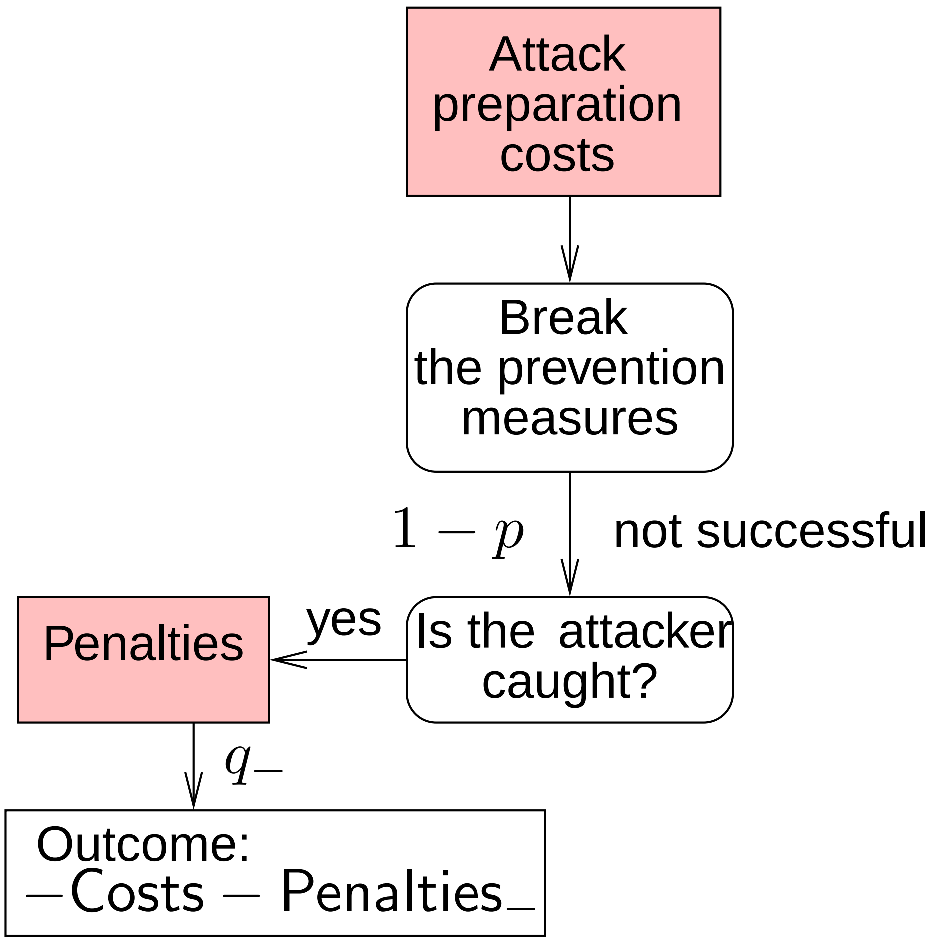

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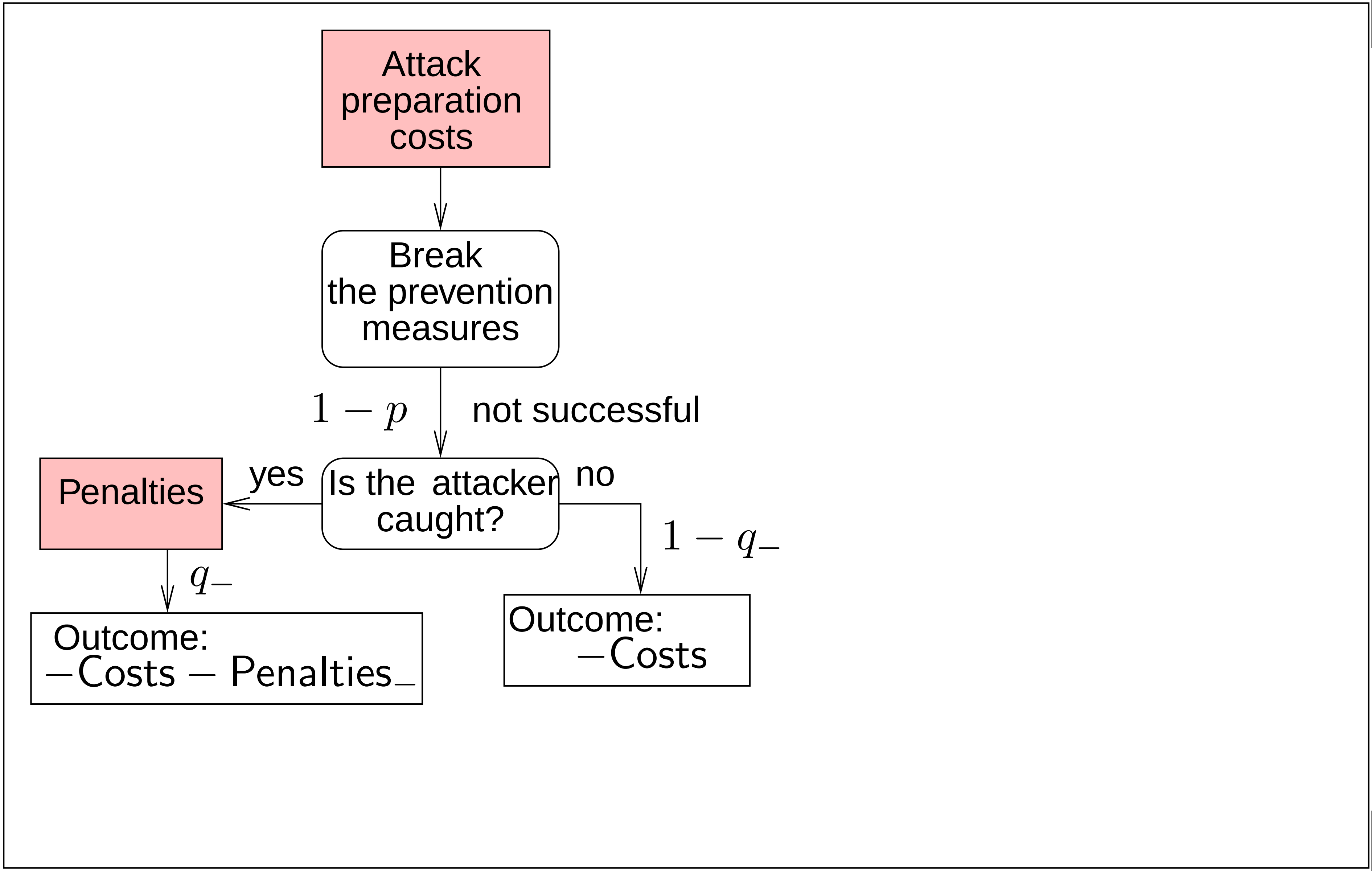

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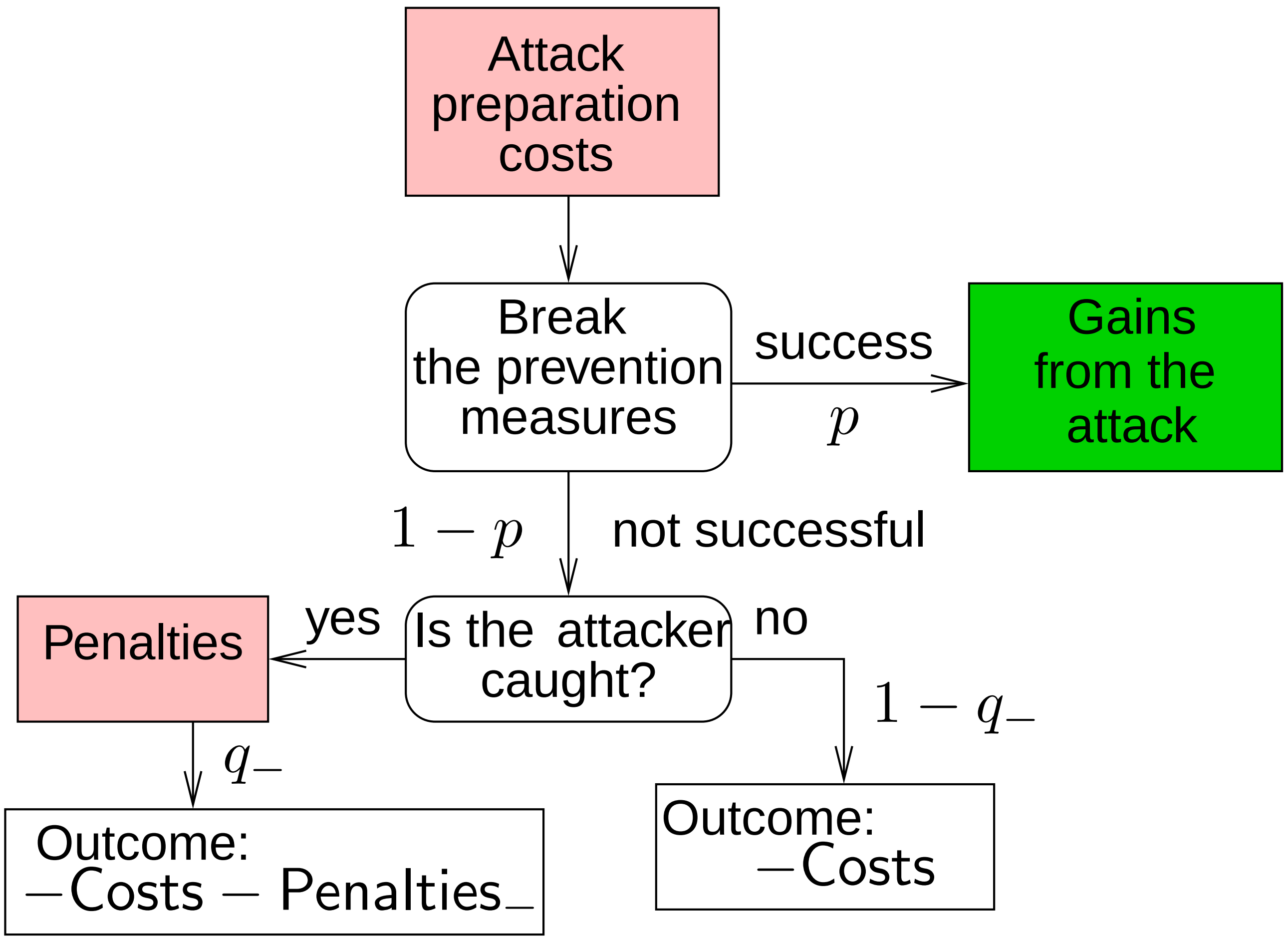

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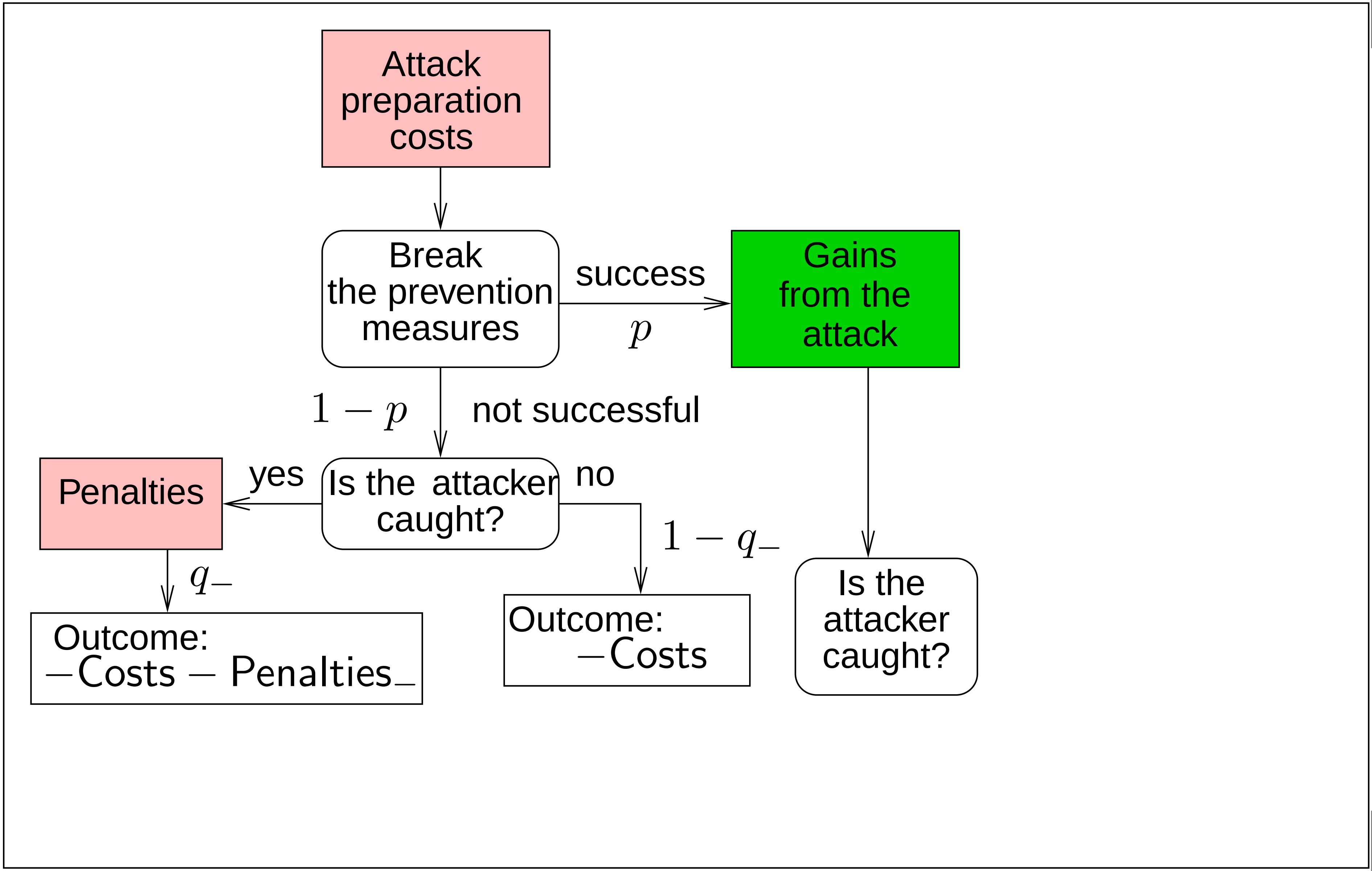

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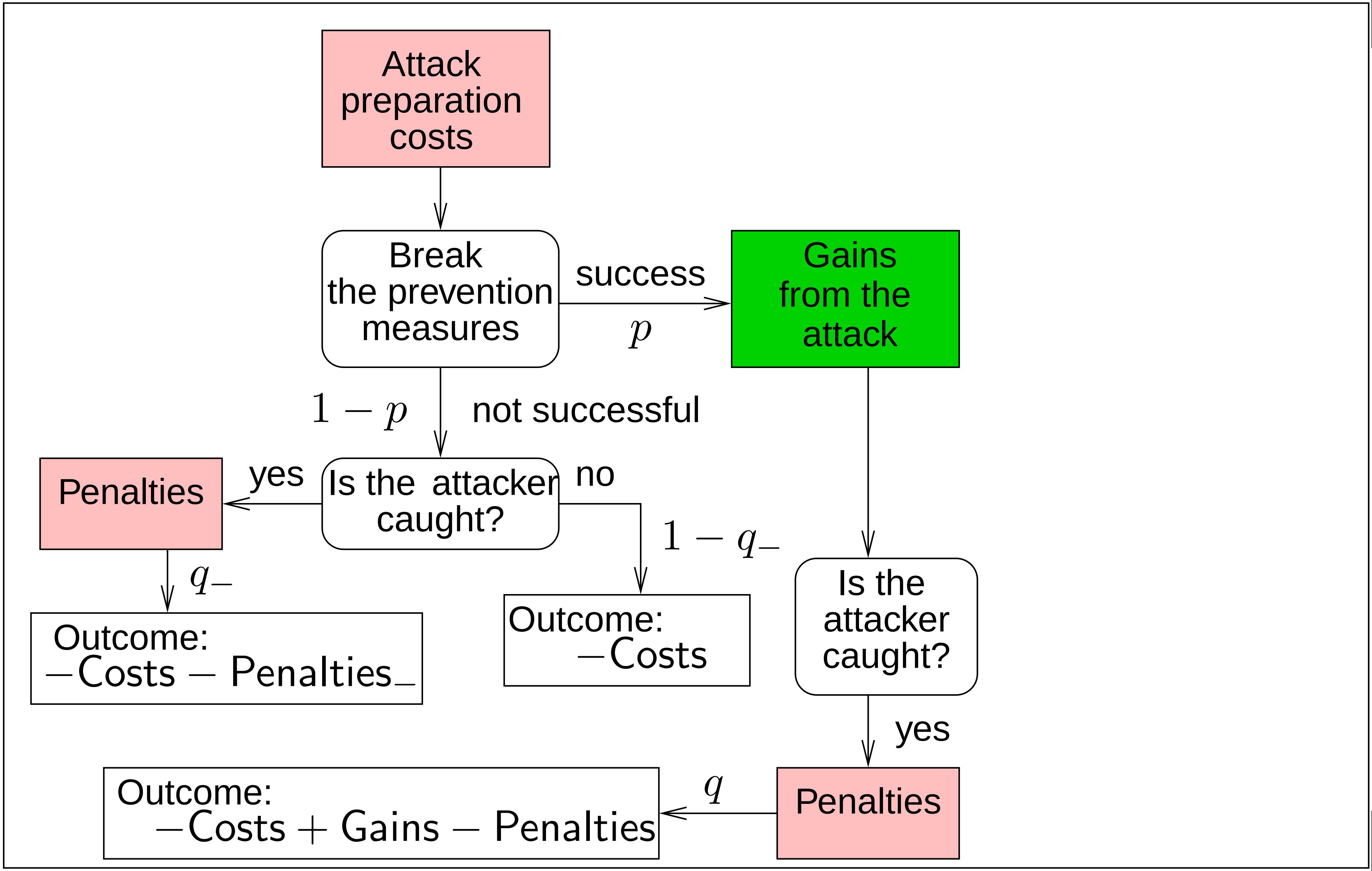

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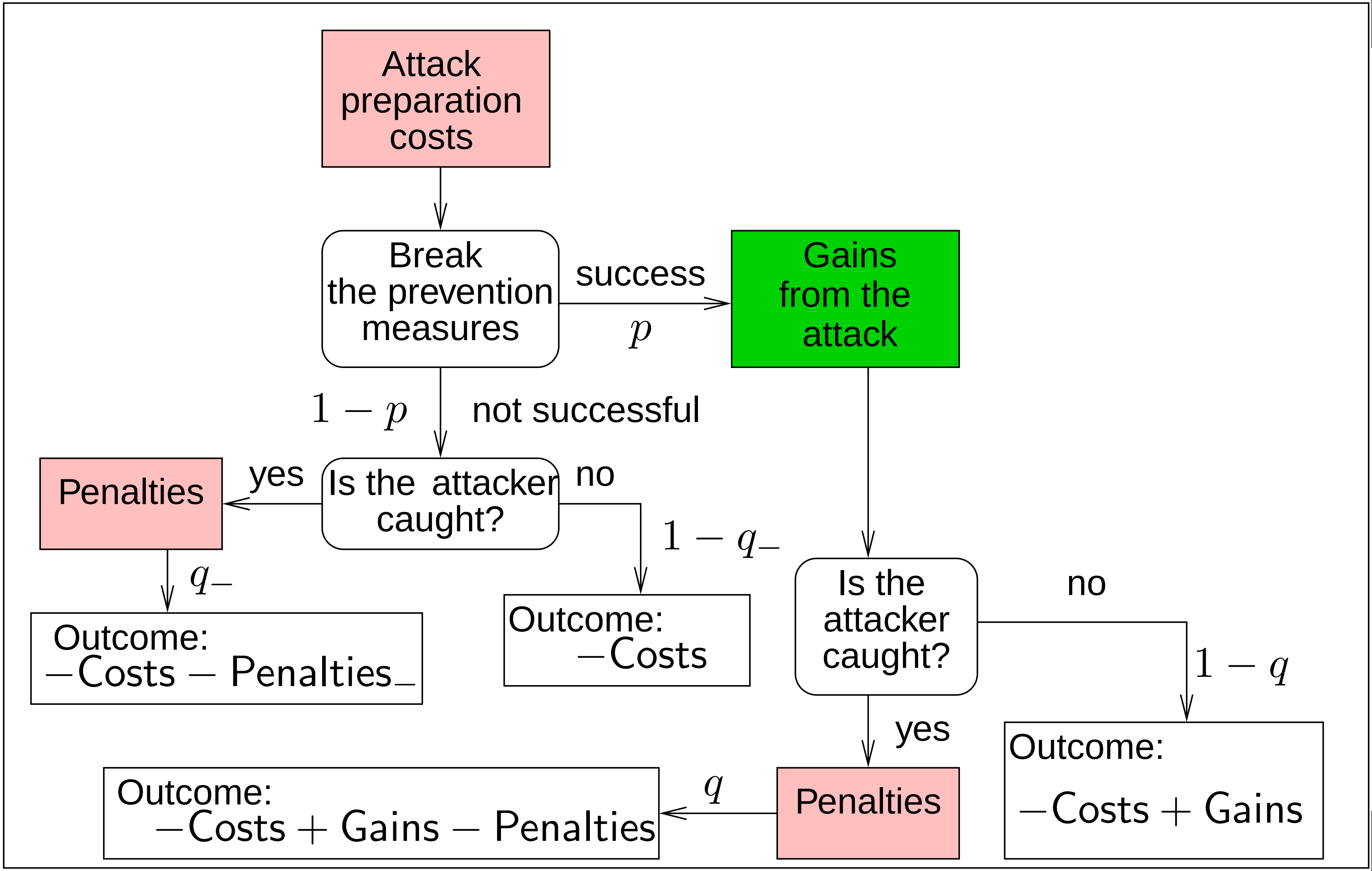

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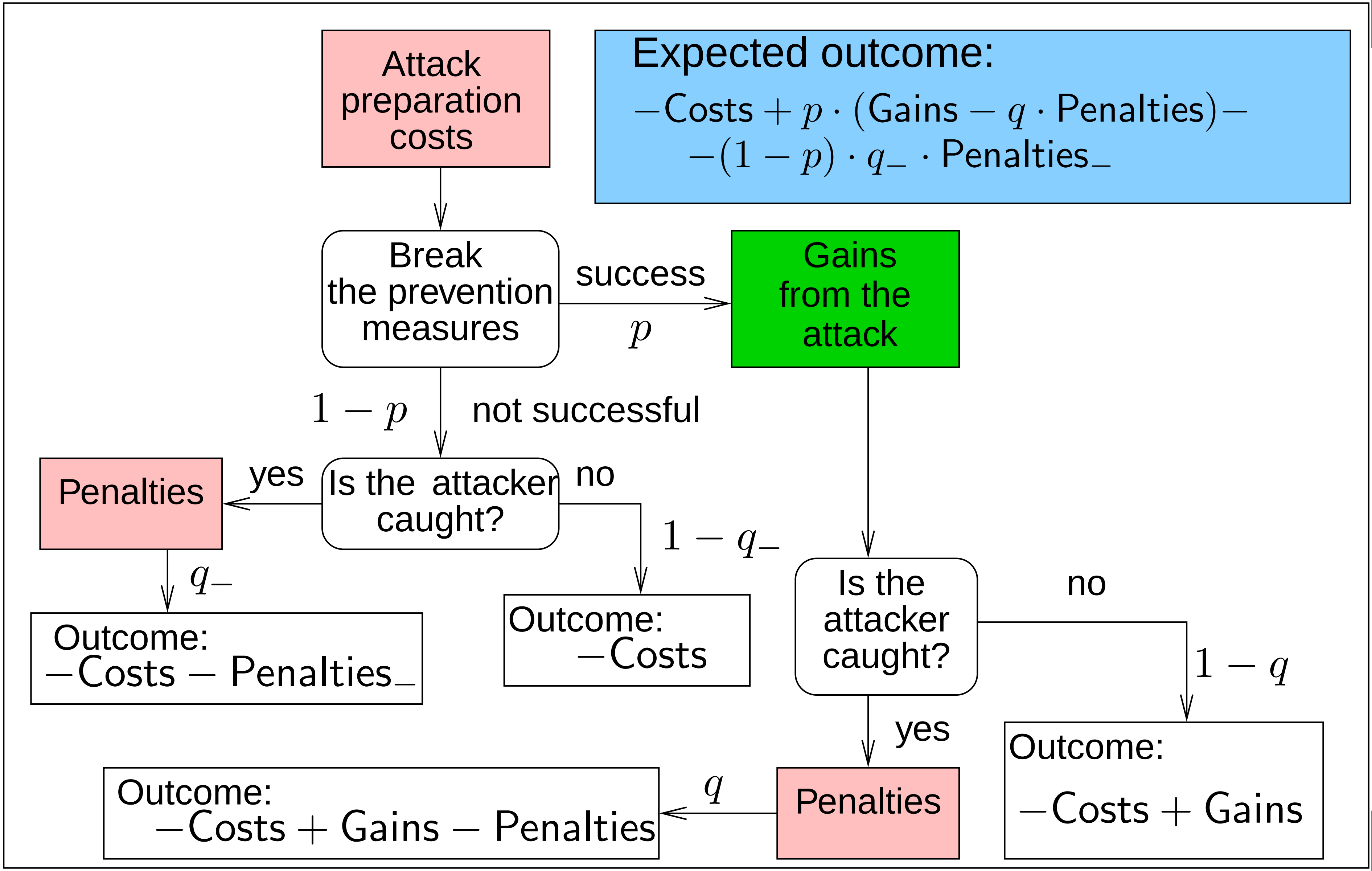


Tree Computations (I)

- Denoting $\pi = q \cdot \mathsf{Penalties}$ and $\pi_- = q_- \cdot \mathsf{Penalties}_-$, we set the parameters $(\mathsf{Costs}, p, \pi, \pi_-)$ for every leaf node. Then we have

$$\mathsf{Outcome} = -\mathsf{Costs}_1 + p \cdot \mathsf{Gains} - p \cdot \pi - (1-p) \cdot \pi_-$$

- For an OR-node with child nodes with parameters $(\mathsf{Costs}_1, p_1, \pi_1, \pi_{1-})$ and $(\mathsf{Costs}_2, p_2, \pi_2, \pi_{2-})$ the parameters $(\mathsf{Costs}, p, \pi, \pi_-)$ are computed as:

$$(\mathsf{Costs}, p, \pi, \pi_-) =$$

$$\begin{cases} (\mathsf{Costs}_1, p_1, \pi_1, \pi_{1-}), & \text{if } \mathsf{Outcome}_1 > \mathsf{Outcome}_2 \\ (\mathsf{Costs}_2, p_2, \pi_2, \pi_{2-}), & \text{if } \mathsf{Outcome}_1 \leq \mathsf{Outcome}_2 \end{cases}$$

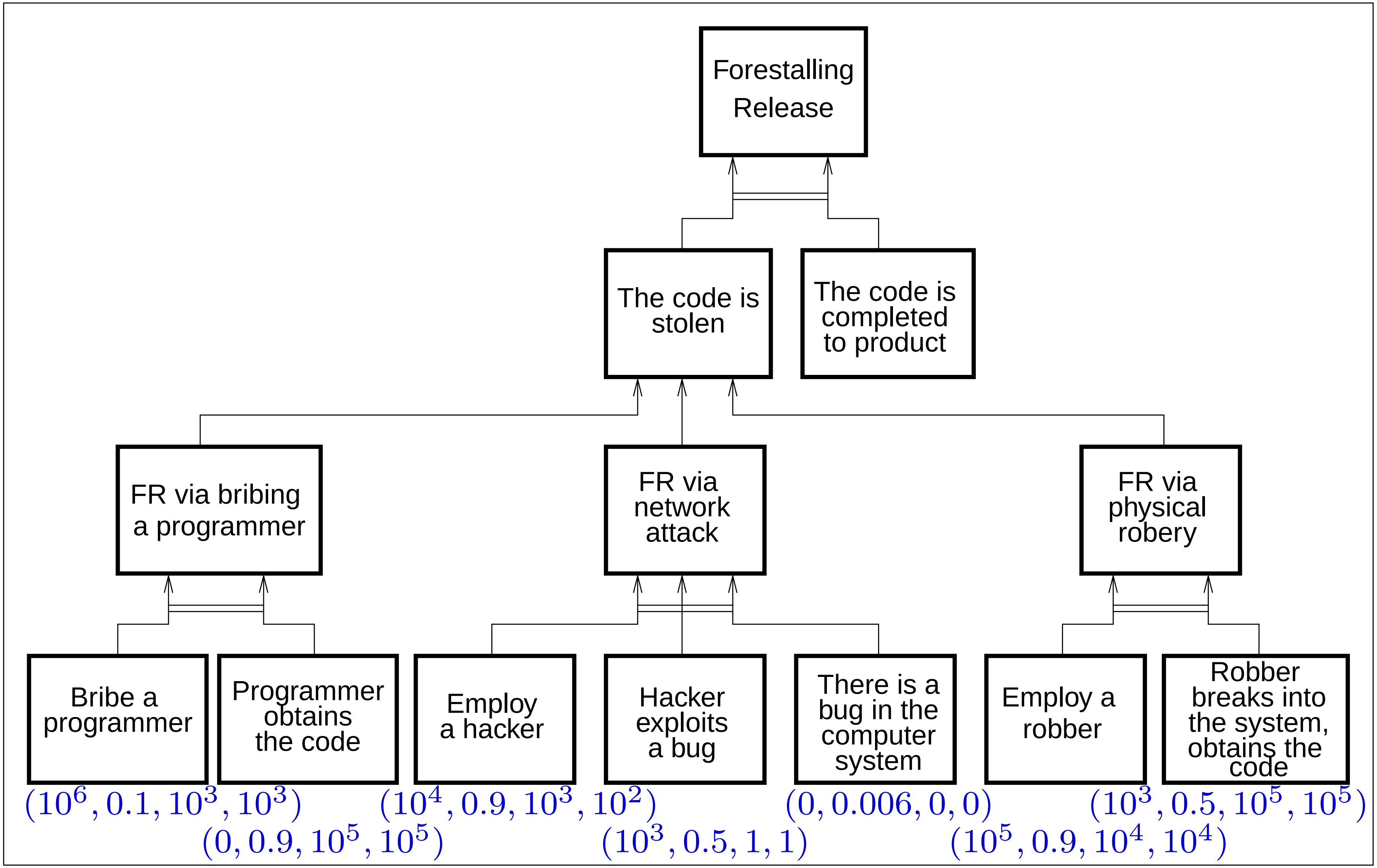
Tree Computations (II)

- For a AND-node with child nodes with parameters $(\mathsf{Costs}_1, p_1, \pi_1, \pi_{1-})$ and $(\mathsf{Costs}_2, p_2, \pi_2, \pi_{2-})$ the parameters $(\mathsf{Costs}, p, \pi, \pi_-)$ are computed as follows:

$$\begin{aligned}
\mathsf{Costs} &= \mathsf{Costs}_1 + \mathsf{Costs}_2 \\
p &= p_1 \cdot p_2 \\
\pi &= \pi_1 + \pi_2 \\
\pi_- &= \frac{p_1(1-p_2)(\pi_1+\pi_{2-}) + (1-p_1)p_2(\pi_{1-}+\pi_2)}{1-p_1p_2} + \\
&\quad \frac{(1-p_1)(1-p_2)(\pi_{1-}+\pi_{2-})}{1-p_1p_2}
\end{aligned}$$

- The last formula represents the average penalty of an attacker, assuming that at least one of the two child-attacks was not successful

Tree Computations: Example



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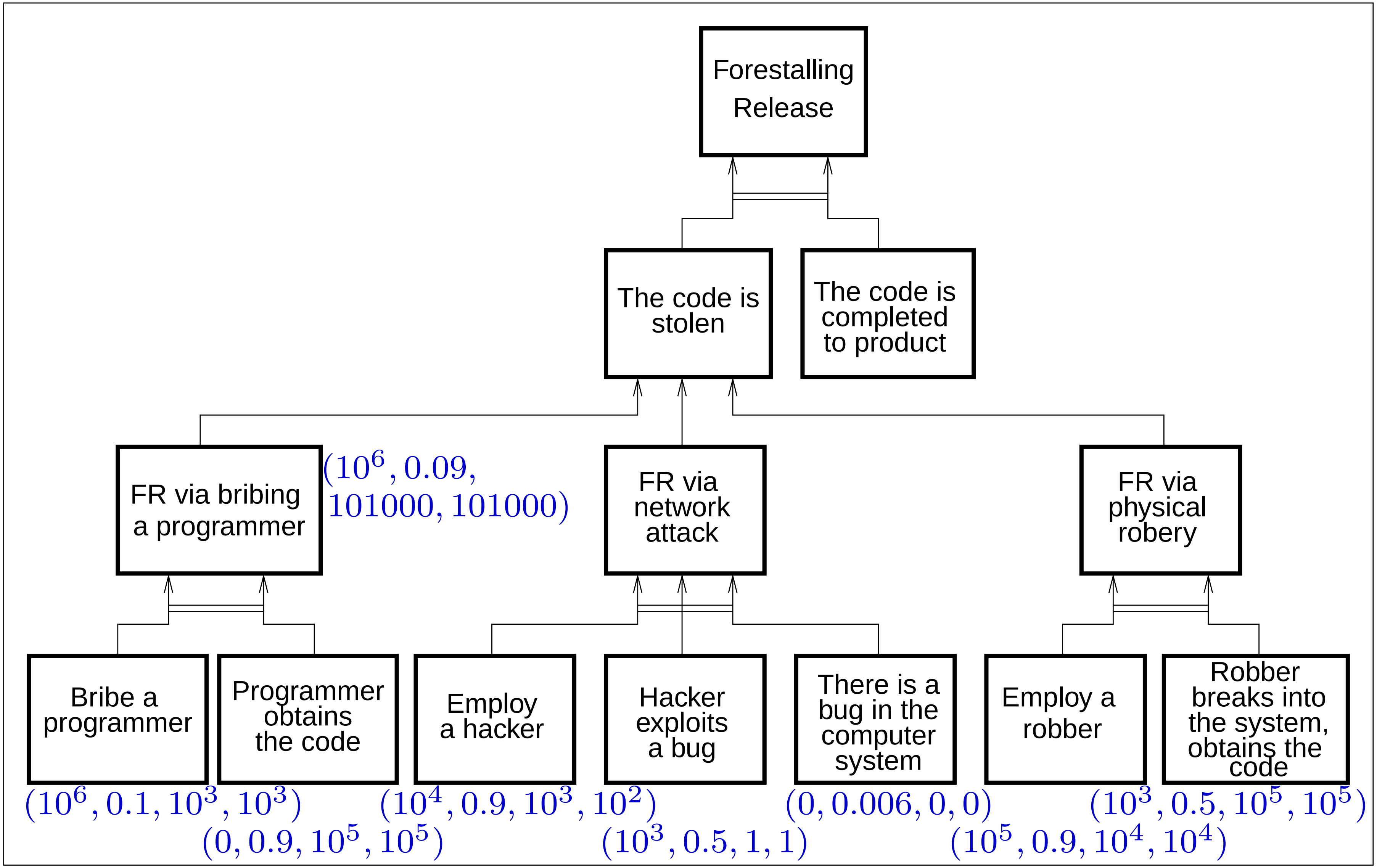

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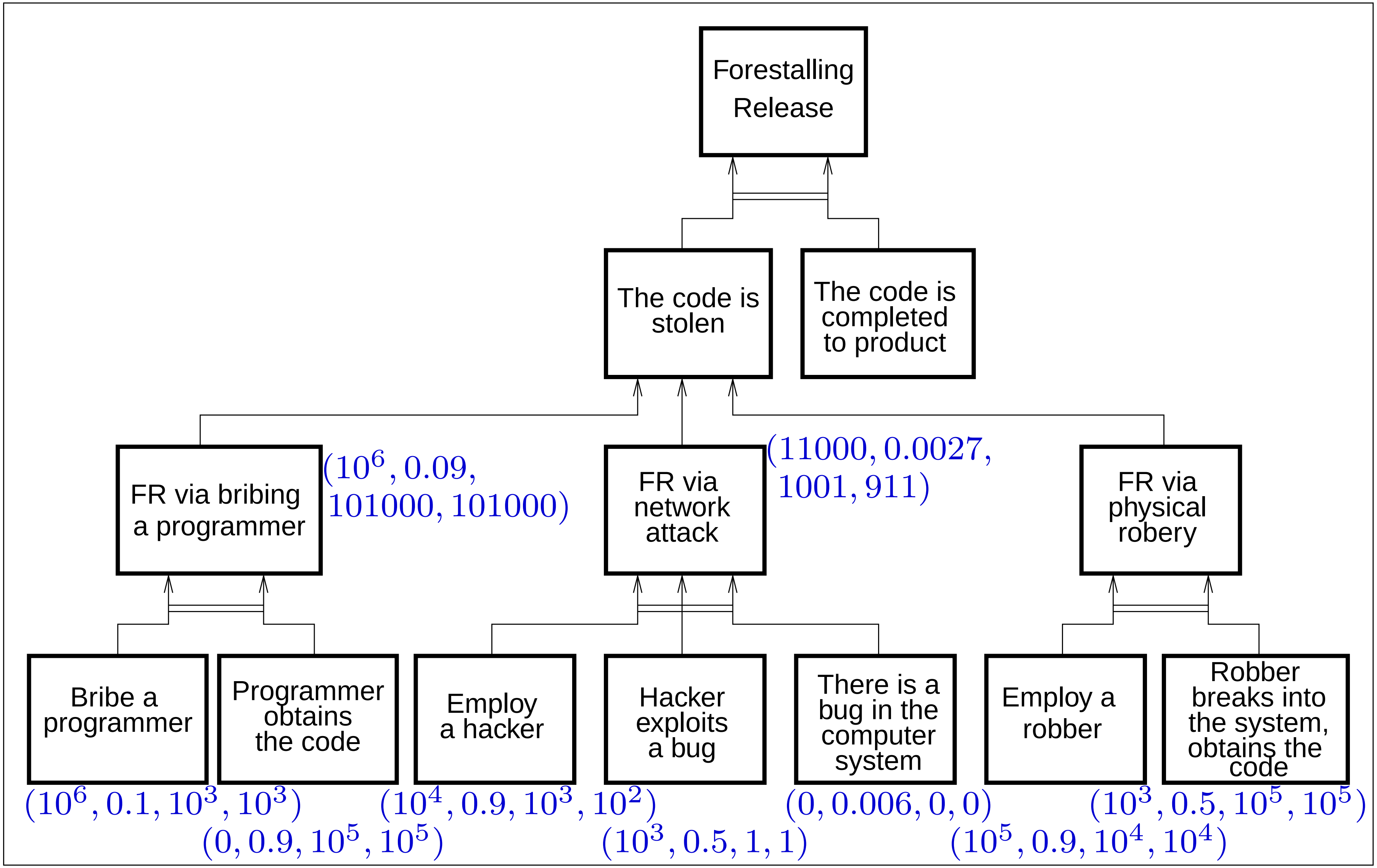

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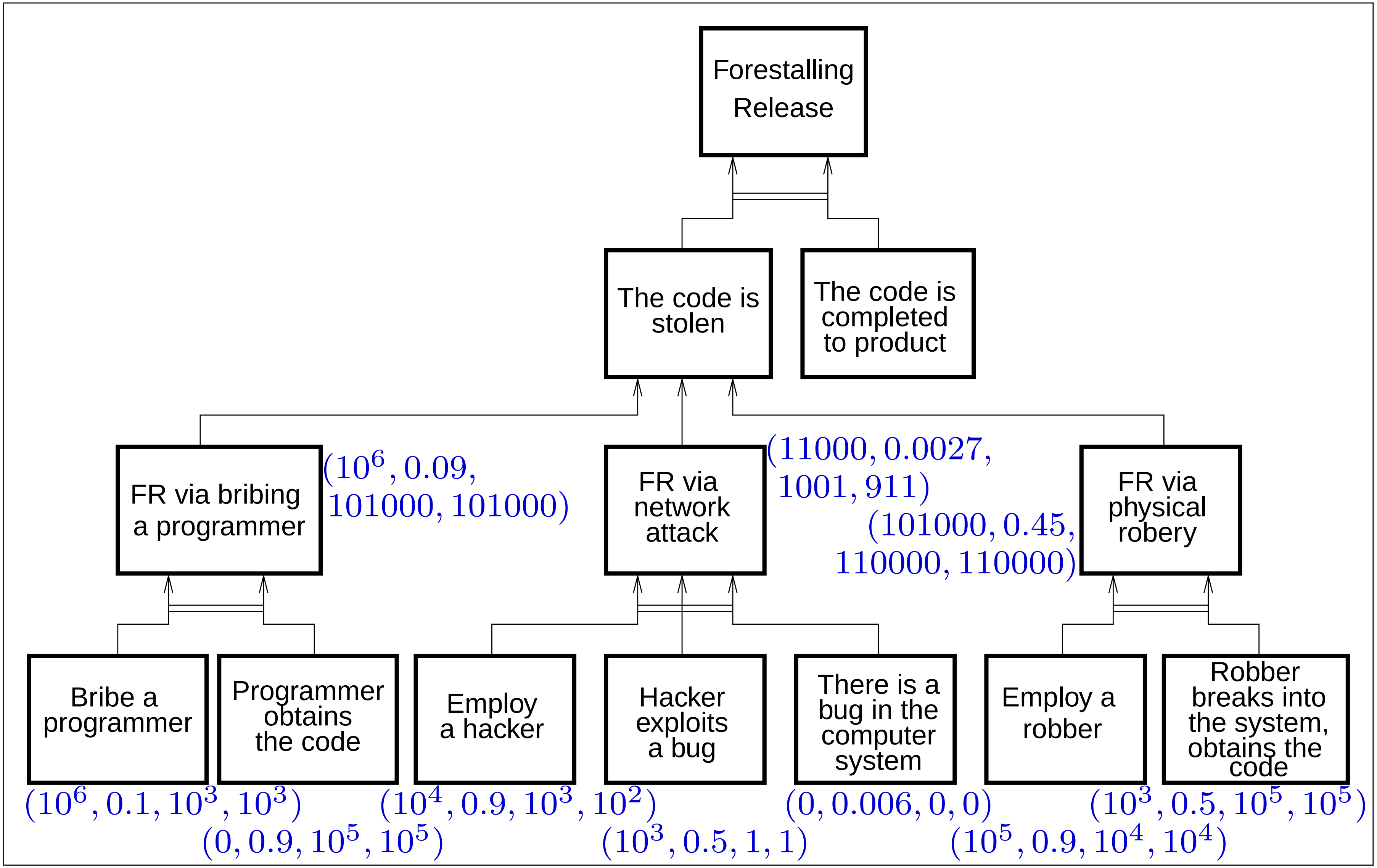

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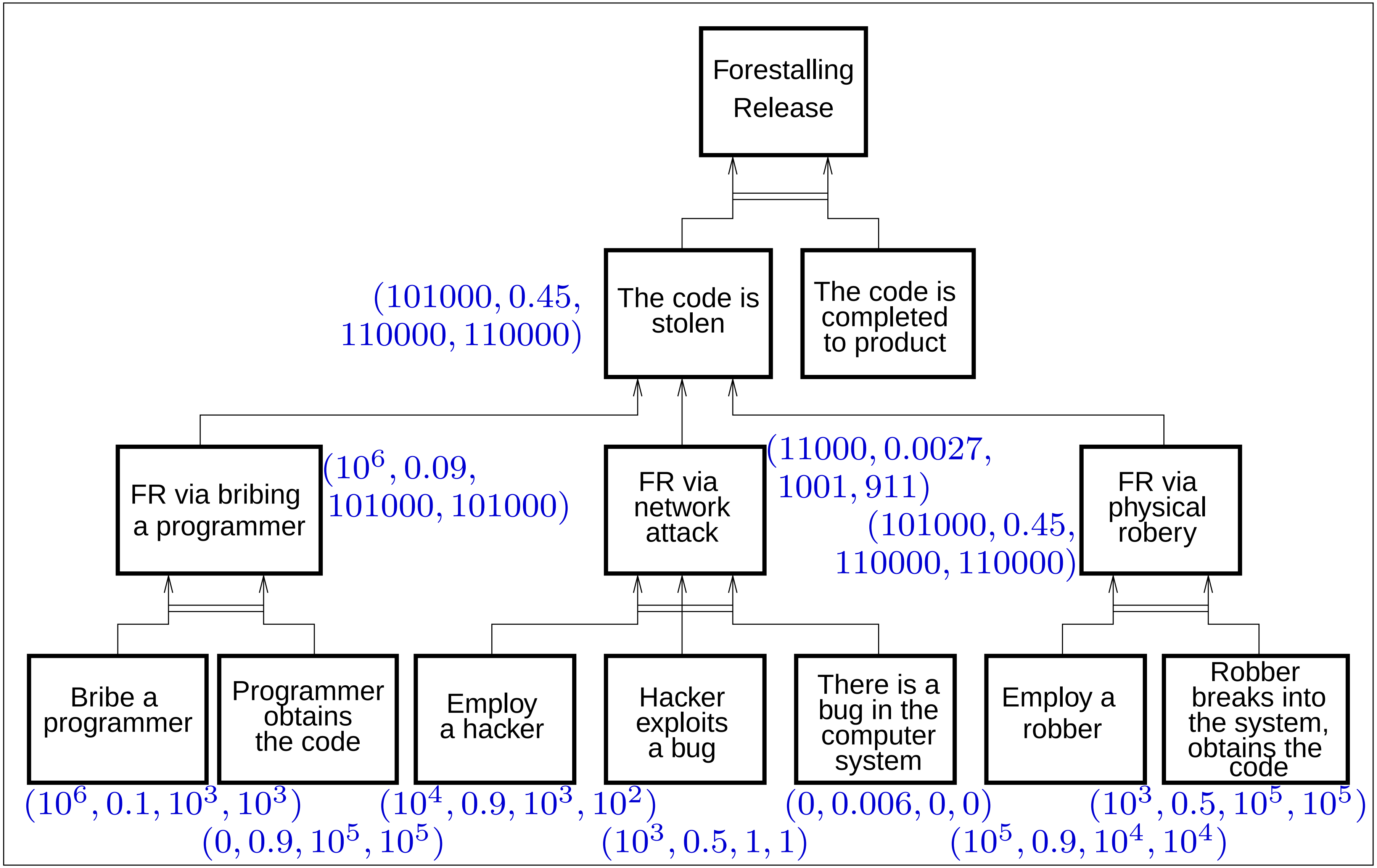

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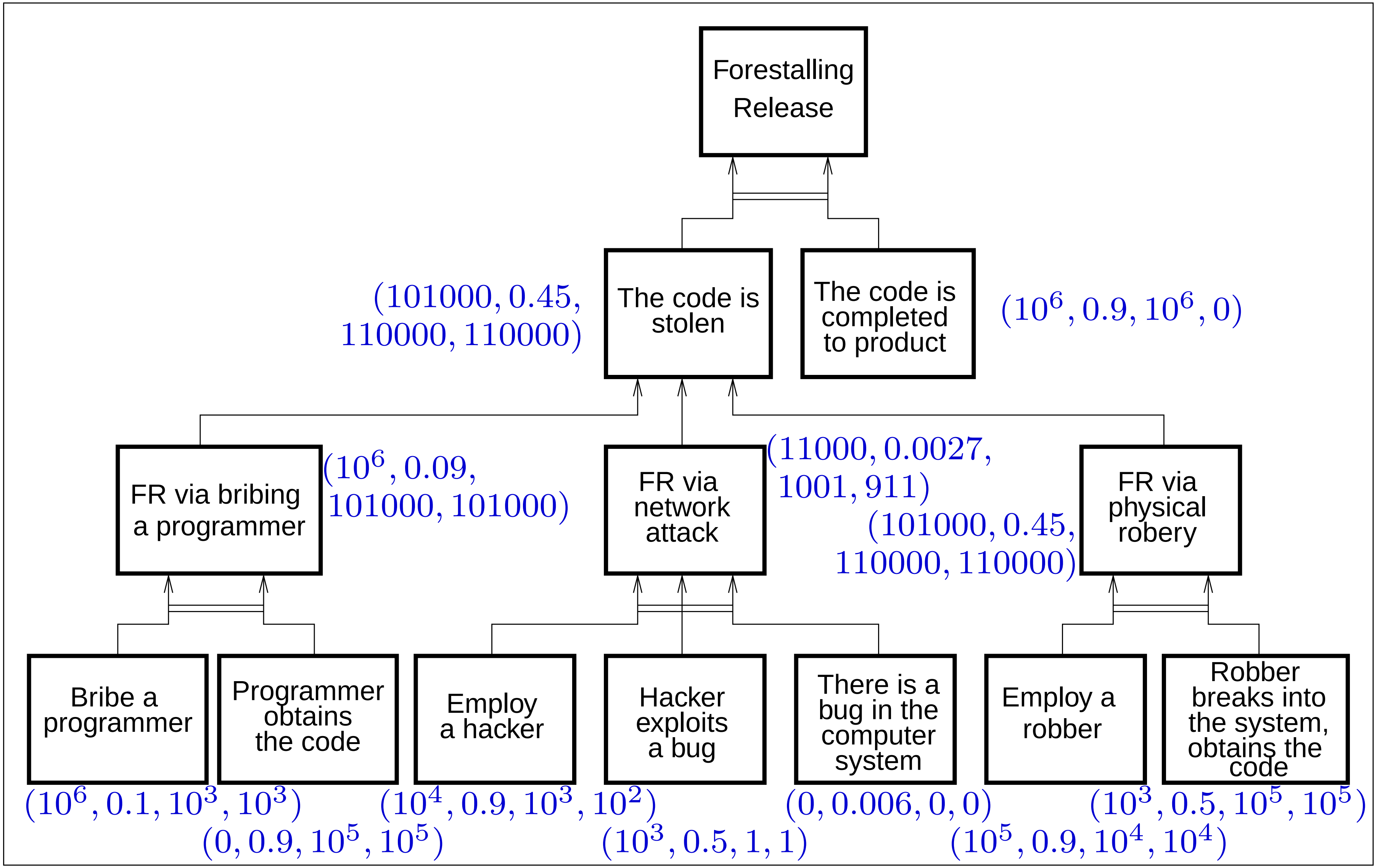

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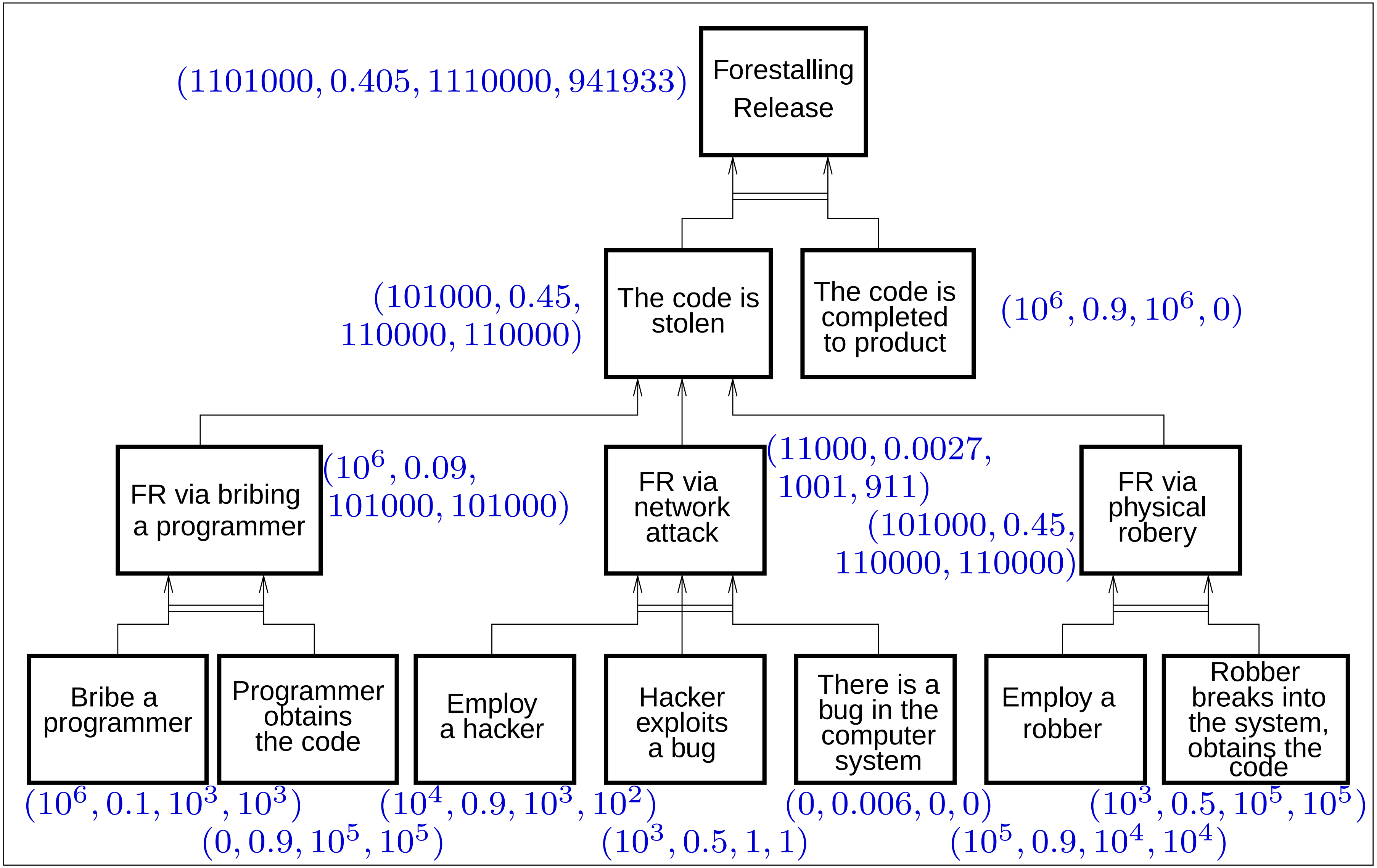

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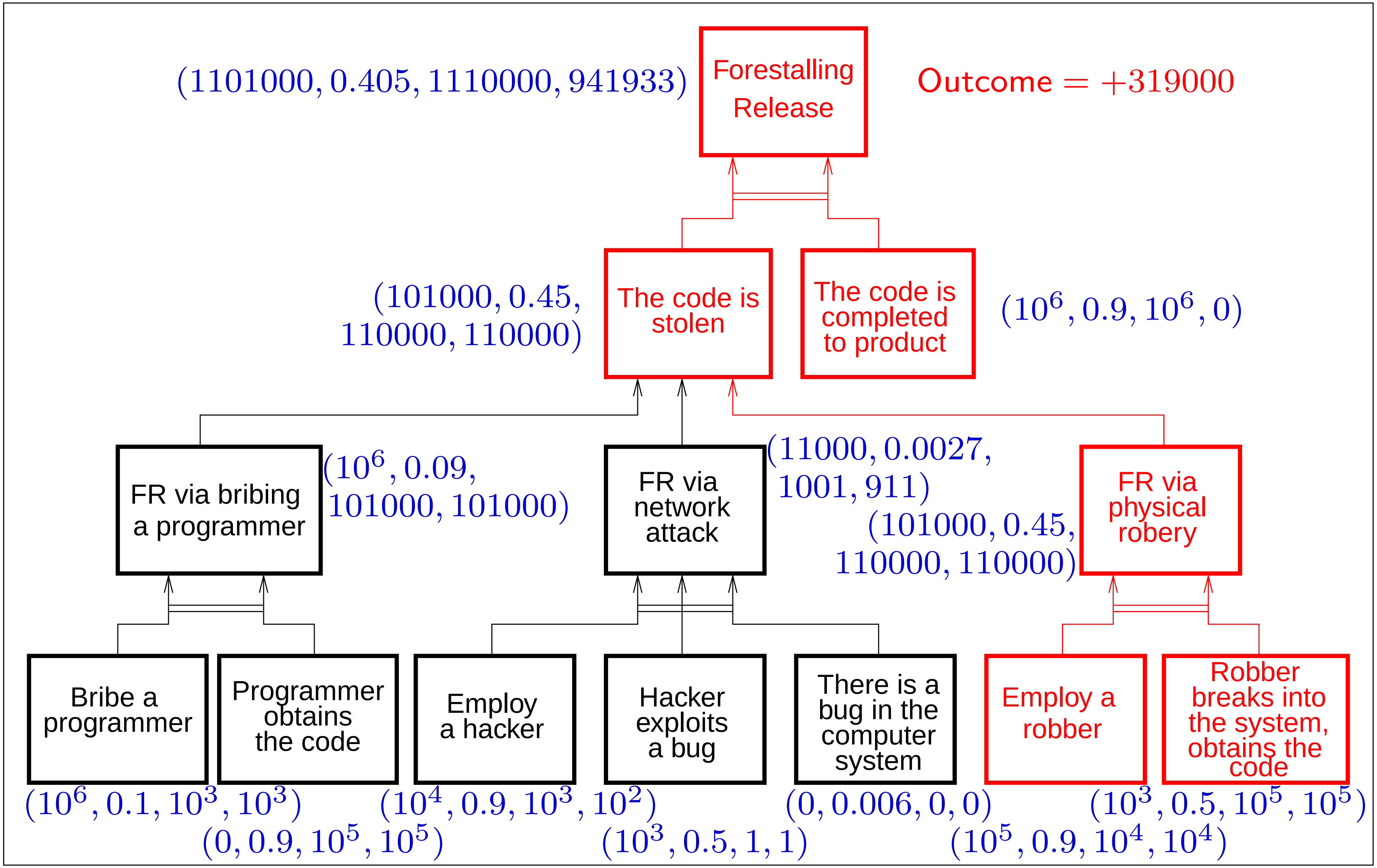


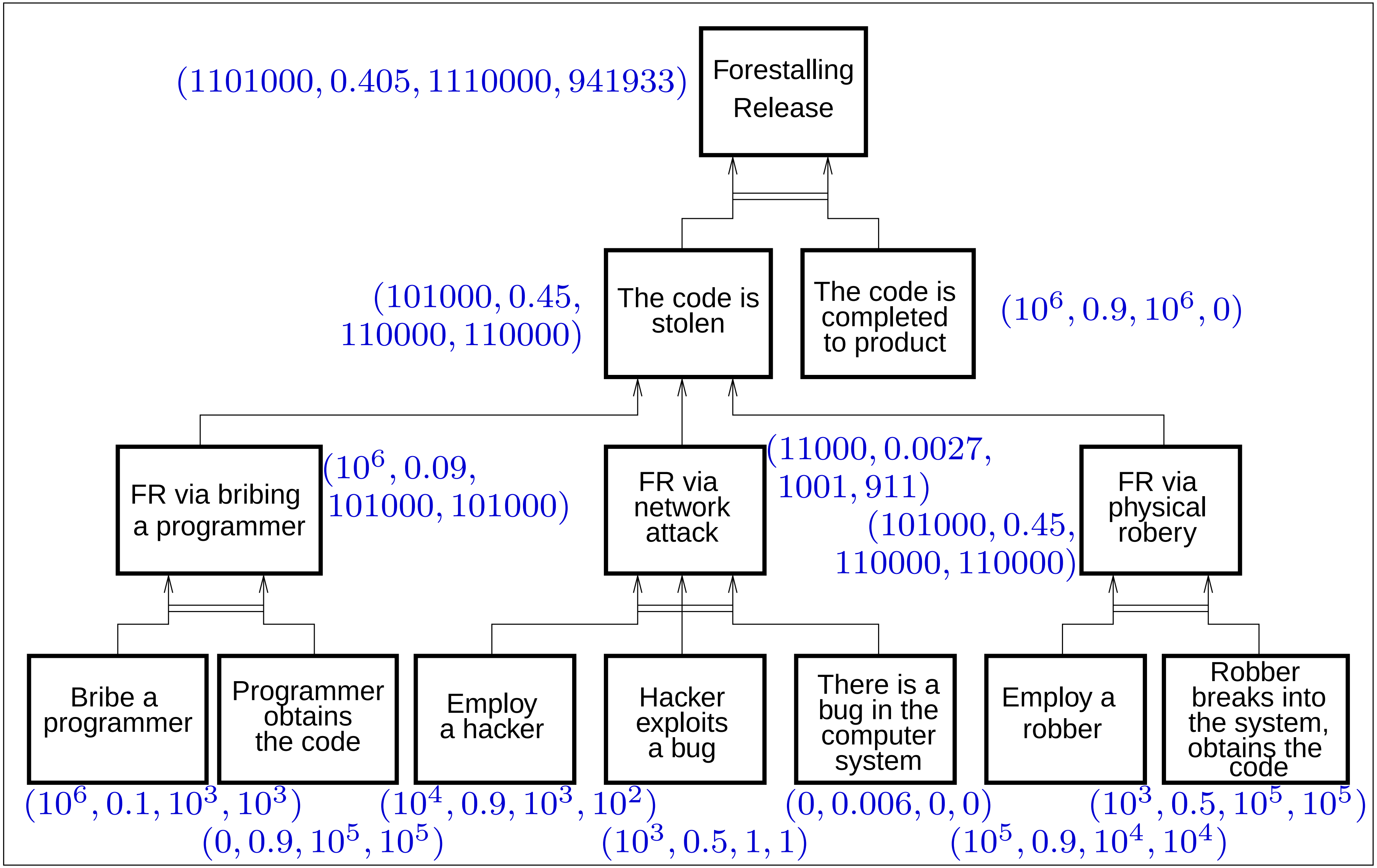
Security Measures

- Let $\mathcal{T}$ denote the set of all *primary threats* and let $\mathcal{M}$ denote some set of security measures
- Let $\mathsf{Loss}[\mathfrak{T}]$ and $\mathsf{Loss}[\mathfrak{T} \mid \mathcal{M}]$ denote the losses of the company without and with the measures, respectively
- Let $\mathsf{Outcome}[\mathcal{T} \mid \mathcal{M}]$ denote the outcome of the game when measures $\mathcal{M}$ are applied
- The set $\mathcal{M}$ of measures is *sufficient (against rational attacks)* if for all primary threats $\mathcal{T} \in \mathfrak{T}$ we have $\mathsf{Outcome}[\mathcal{T} \mid \mathcal{M}] \leq 0$, or equivalently, $\mathsf{Loss}[\mathfrak{T} \mid \mathcal{M}] = 0$
- The set $\mathcal{M}$ of measures is *adequate* (worth its cost) if $\mathsf{Loss}[\mathfrak{T}] - \mathsf{Loss}[\mathfrak{T} \mid \mathcal{M}] > \mathsf{Cost}[\mathcal{M}]$

Example continued

- Let us consider two potential sets of security measures:
  - The set $\mathcal{M}_X$ with price $\mathsf{Cost}[\mathcal{M}_X] = \$2,000,000$ reducing the probability of break-in from 0.5 to 0.25
  - The set $\mathcal{M}_Y$ with price $\mathsf{Cost}[\mathcal{M}_Y] = \$1,000,000$ increasing the detection probabilities (hence also the parameters π and π_-) twice
- Provided both sets are adequate, are they also sufficient?

Example: Set $\mathcal{M}_X$



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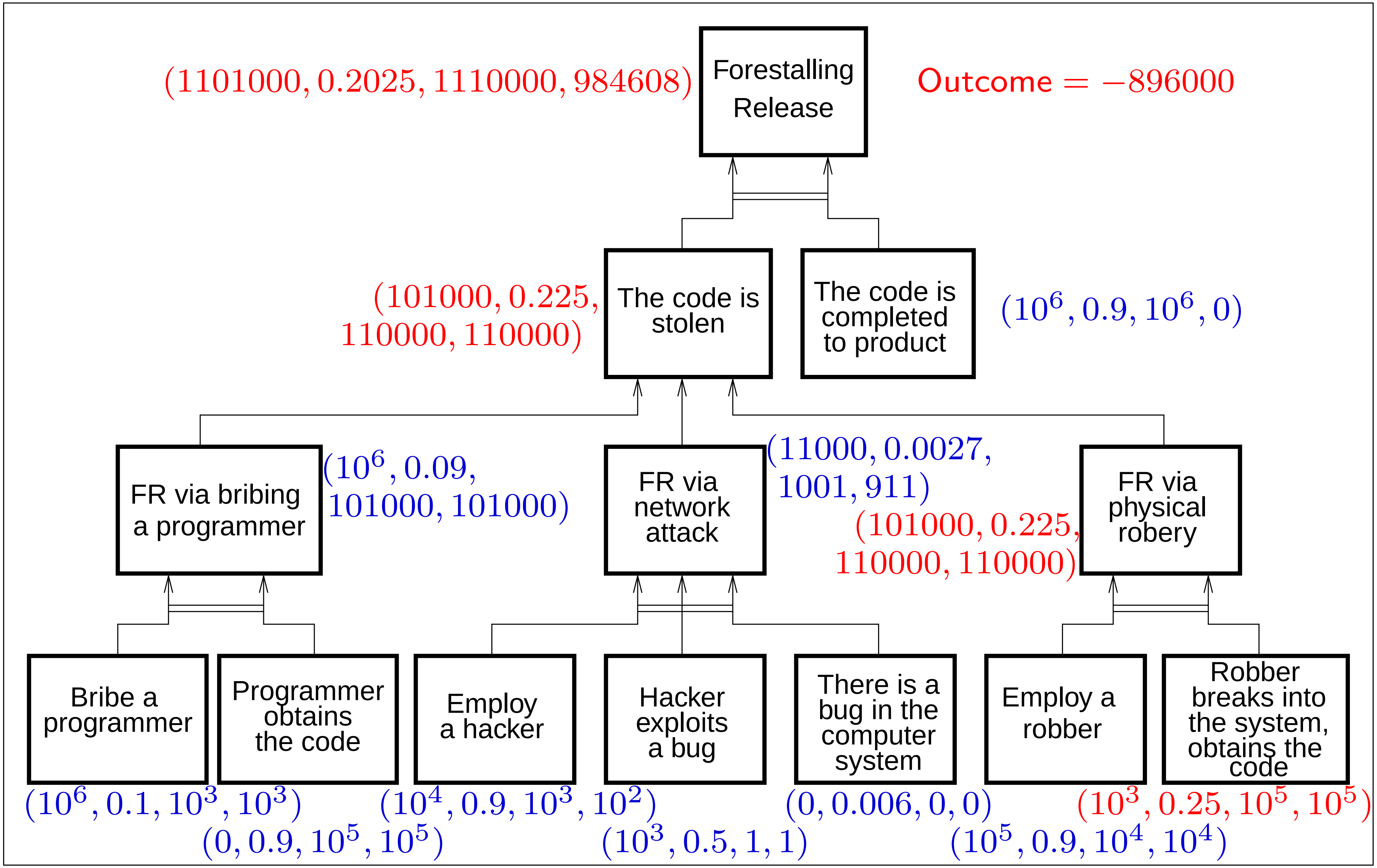
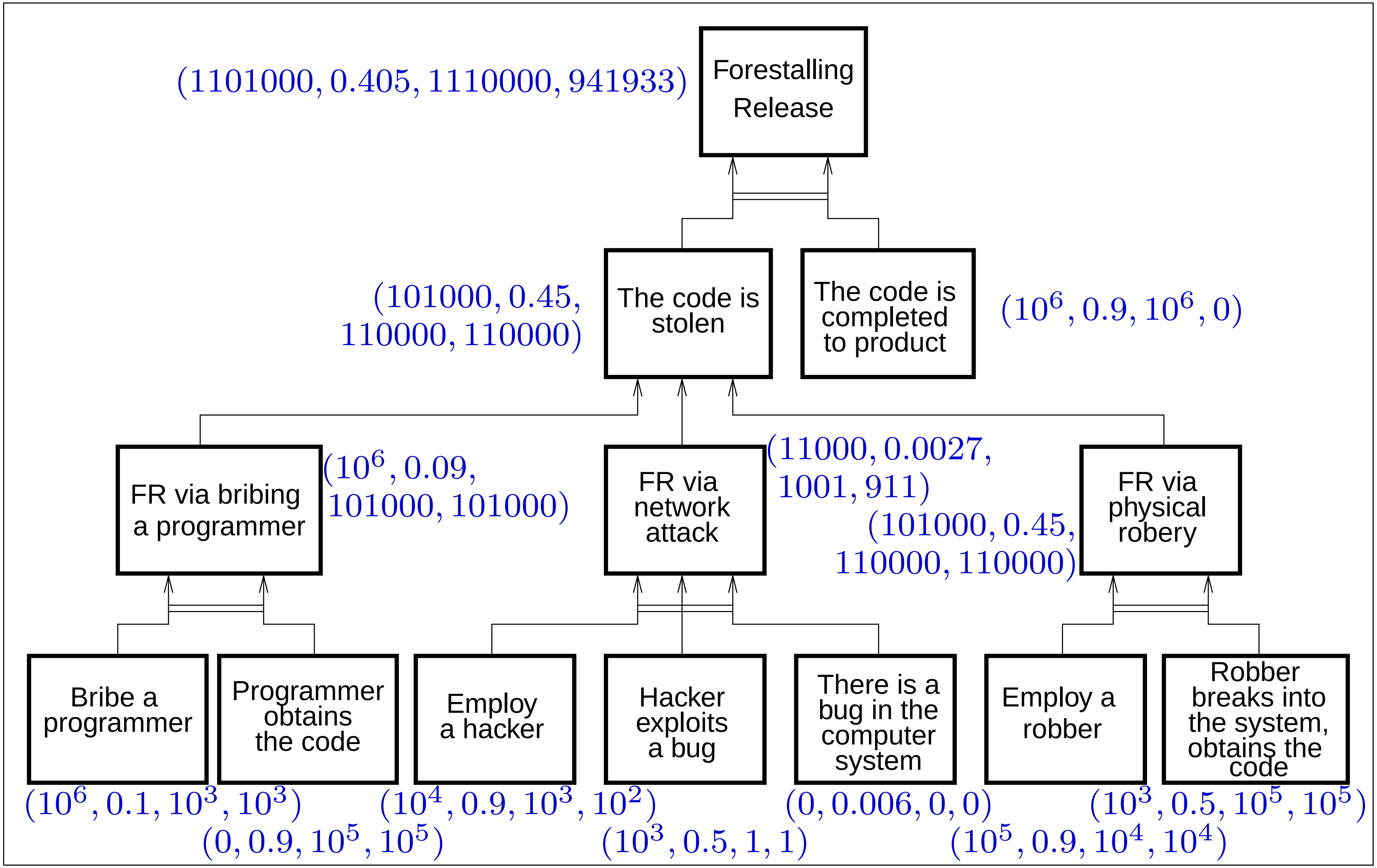


Example: Set $\mathcal{M}_Y$



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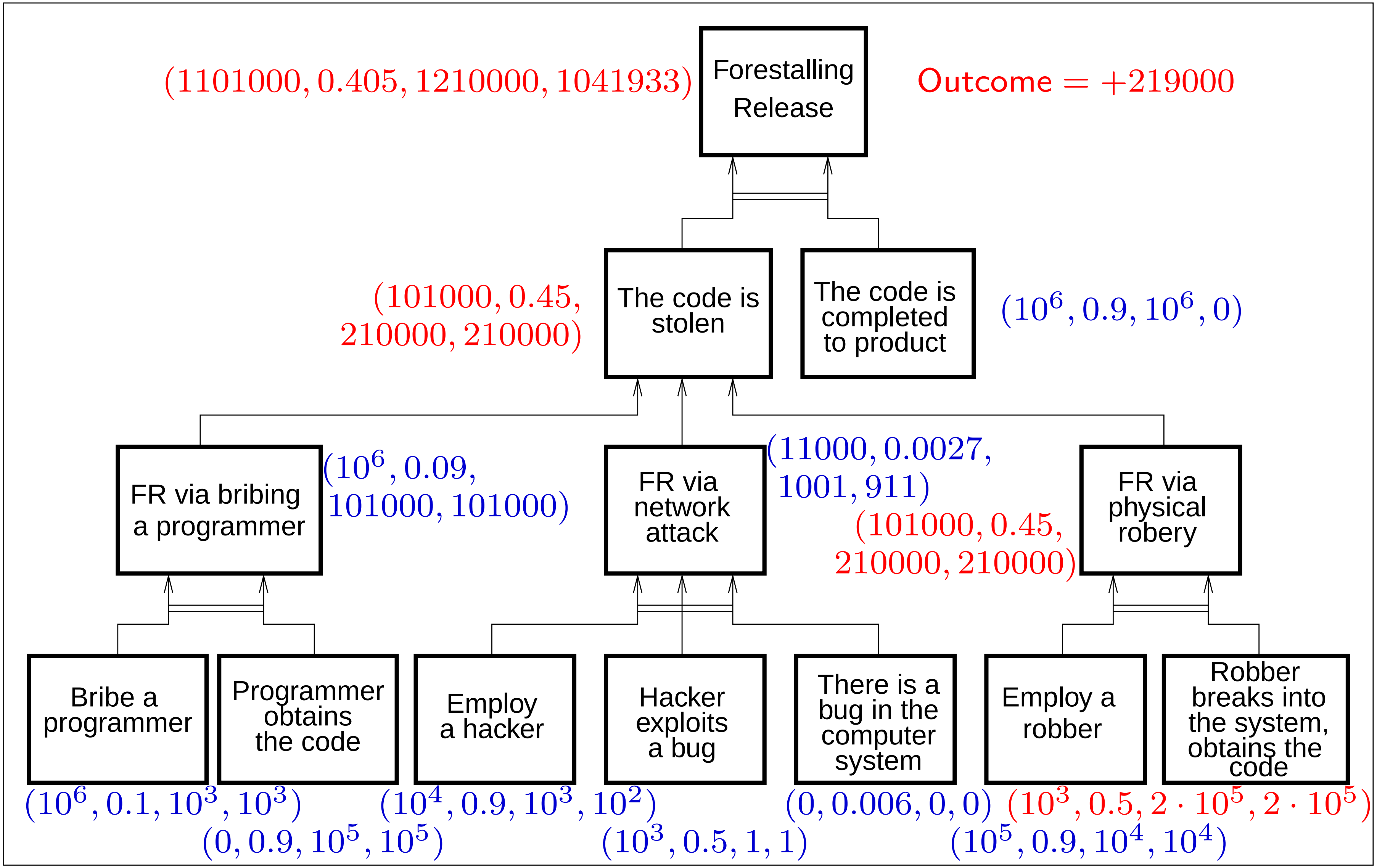

Conclusions

- Our contributions:
  - We have considered multi-parameter attack trees with interdependent parameters
  - We have shown how such trees can be used to make security decisions against rational attackers
- Problems to study further:
  - Gains is a global parameter, making the computations in OR-nodes imprecise
  - Dependencies between different child nodes

Thank You!

Questions?