# An Expert System for Automatic Software Protection

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XXXI cycle

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# Why is software security needed?

- software is used in (almost) every aspect of everyday life
  - e-banking, entertainment, e-government and many more

- attacks on weakly or non-protected software have a great impact on software companies
  - loss of intellectual property
  - loss of revenues: 46 billions $ in 2018[1]

- using unlicensed software is dangerous
  - malware usually contained in pirated software
  - disclosure of sensitive data and/or identity theft

[1]2018 BSA Global Security Survey: https://gss.bsa.org/

# Software protection techniques

- objective: safeguard *security requirements* of software *assets*
  - assets: algorithms IP, license schemes, users´ data…
  - security requirements: confidentiality, integrity

- Man At The End (MATE) scenario
  - attacker has white-box access to application

- no perfect software protection exists
  - but protections can defer attacks

# How to protect the software?

- protections decided and applied manually/empirically: several issues
  - long and complex vulnerability analysis
  - high expertise needed to choose the best protections
  - different platform+OS require different analysis

- an automatic approach? desirable
  - for the expert: can provide a good starting point
  - for the beginner: one click and do everything

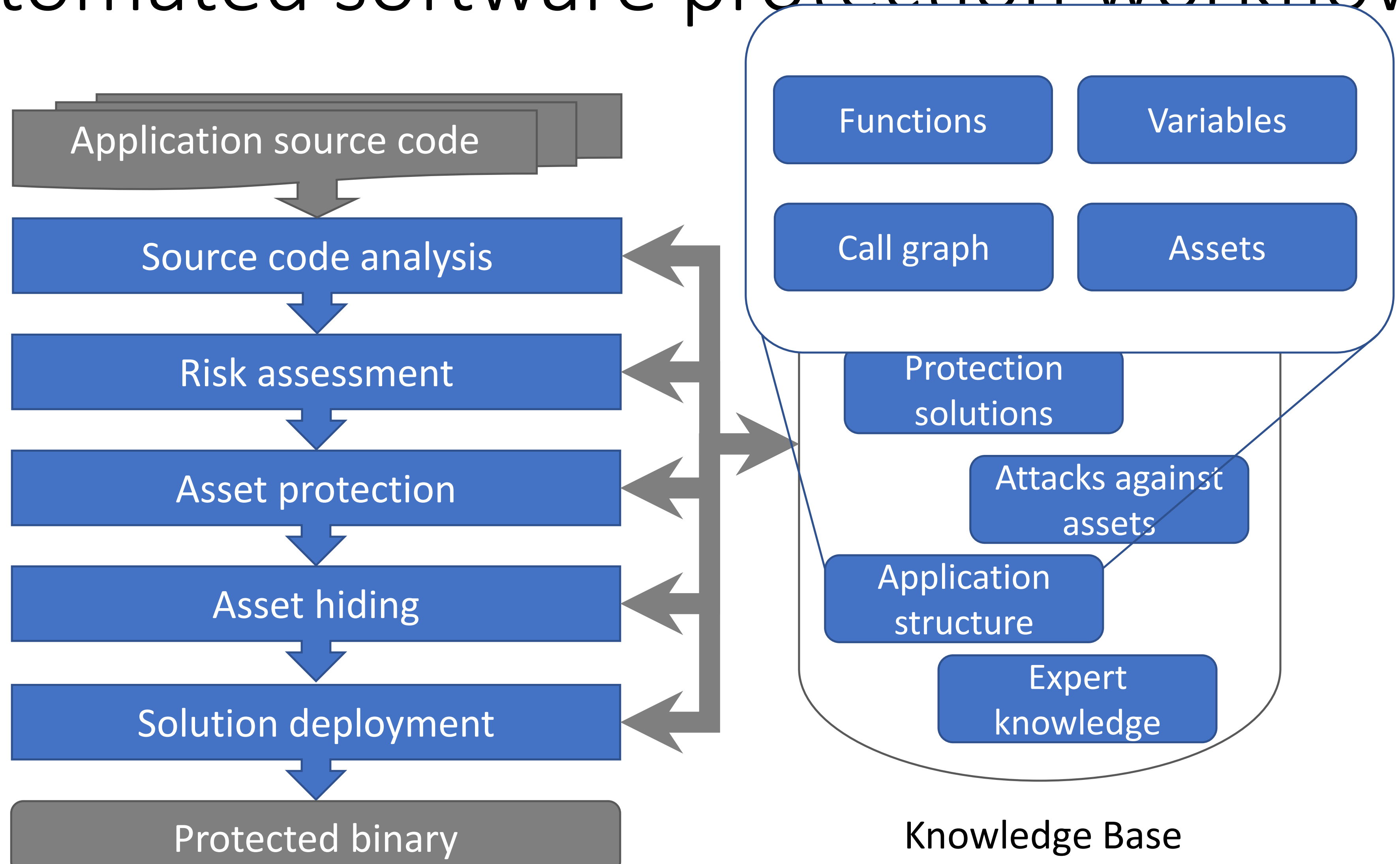
# Expert system for Software Protection (ESP)

- objective: provide an optimal *protection solution* for a given application
  - decide protections best able to safeguard the application assets
  - preserving the user experience

- can drive automatic protection tools
  - for a fully automated protection workflow

- implemented as a set of Eclipse plug-ins

# Automated software protection workflow



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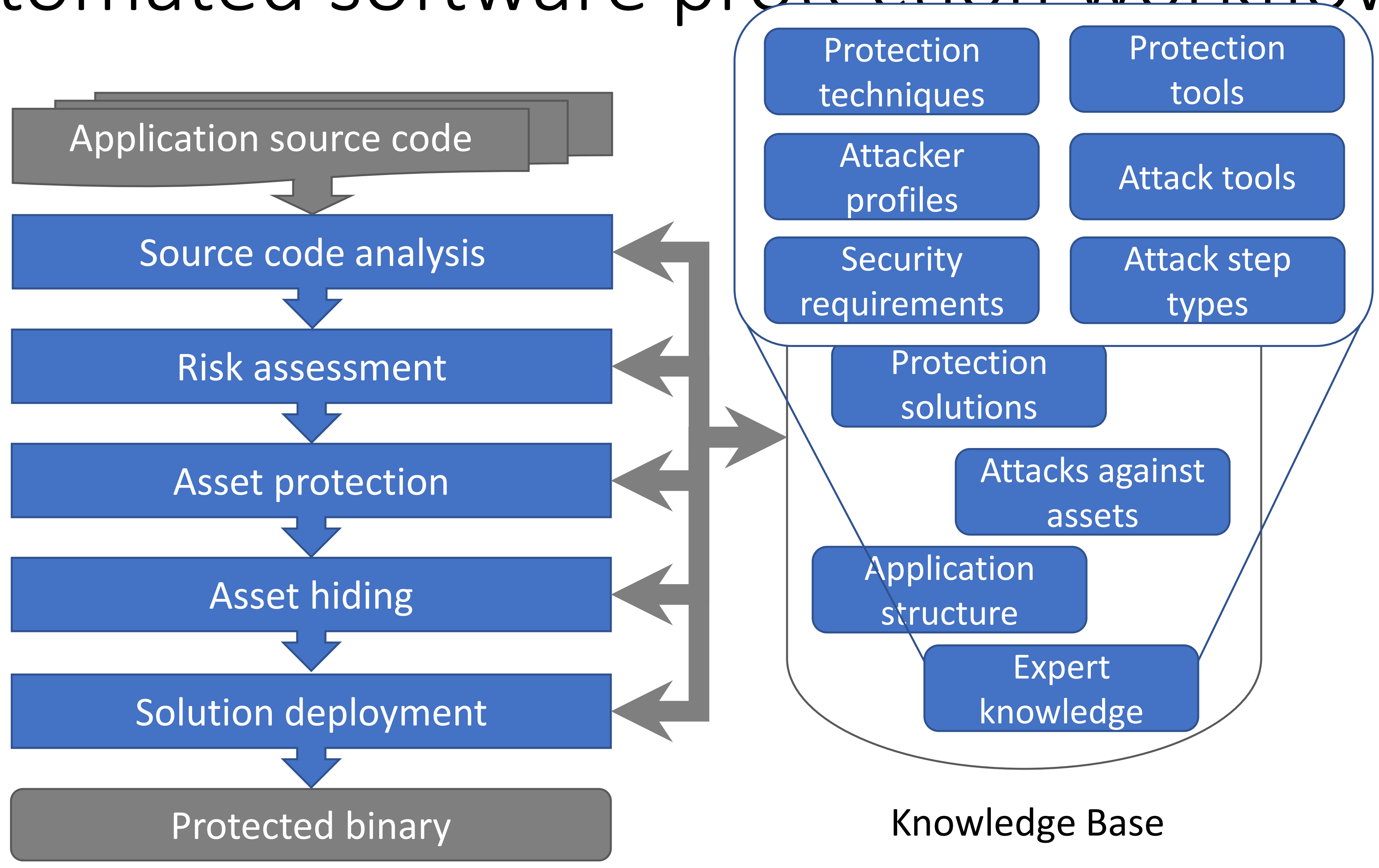
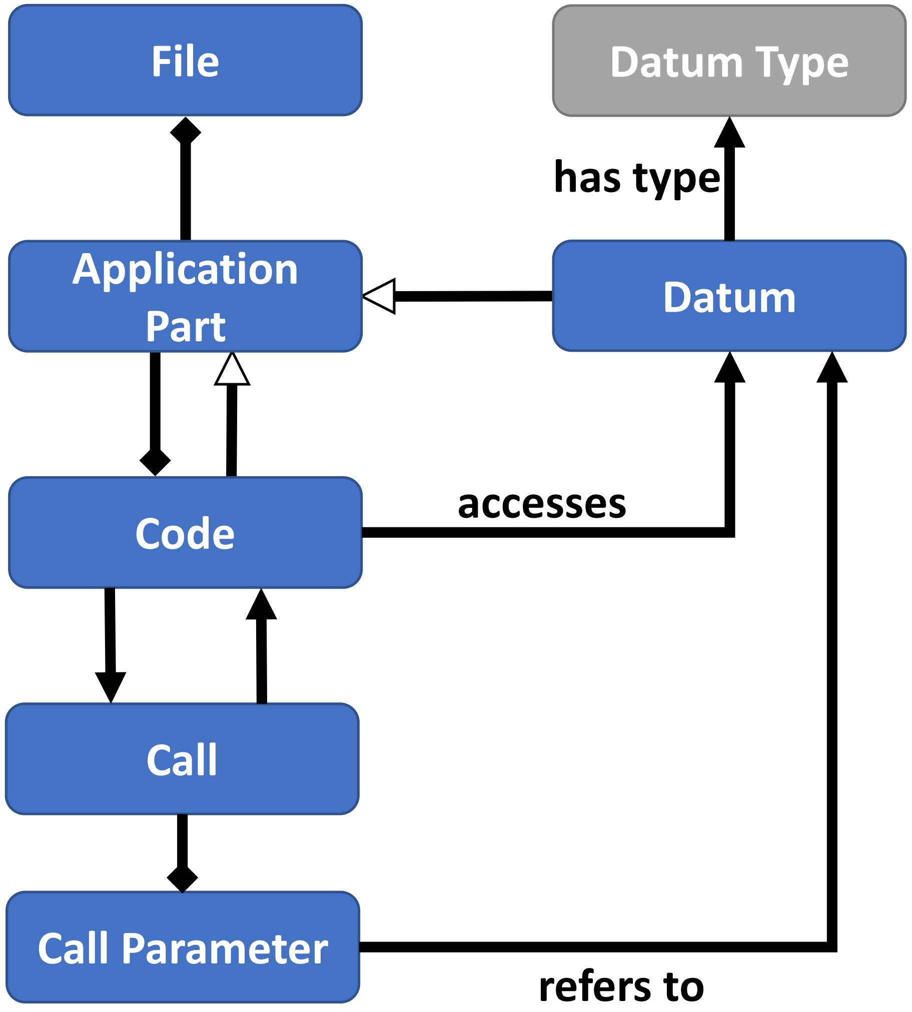


# Software security meta-model[4]

- formalizes all data handled by expert system
  - software security experts' general knowledge
  - application-specific data
  - results of expert system
- OWL2 ontology
- classes and associations to describe:
  - application structure
  - assets and security requirements
  - attacks against assets
  - protections




[4]C. Basile, D. Canavese, L. Regano, P. Falcarin, B. De Sutter, A meta-model for software protections and reverse engineering attacks, *Journal of Systems and Software, Volume 150*, 2019

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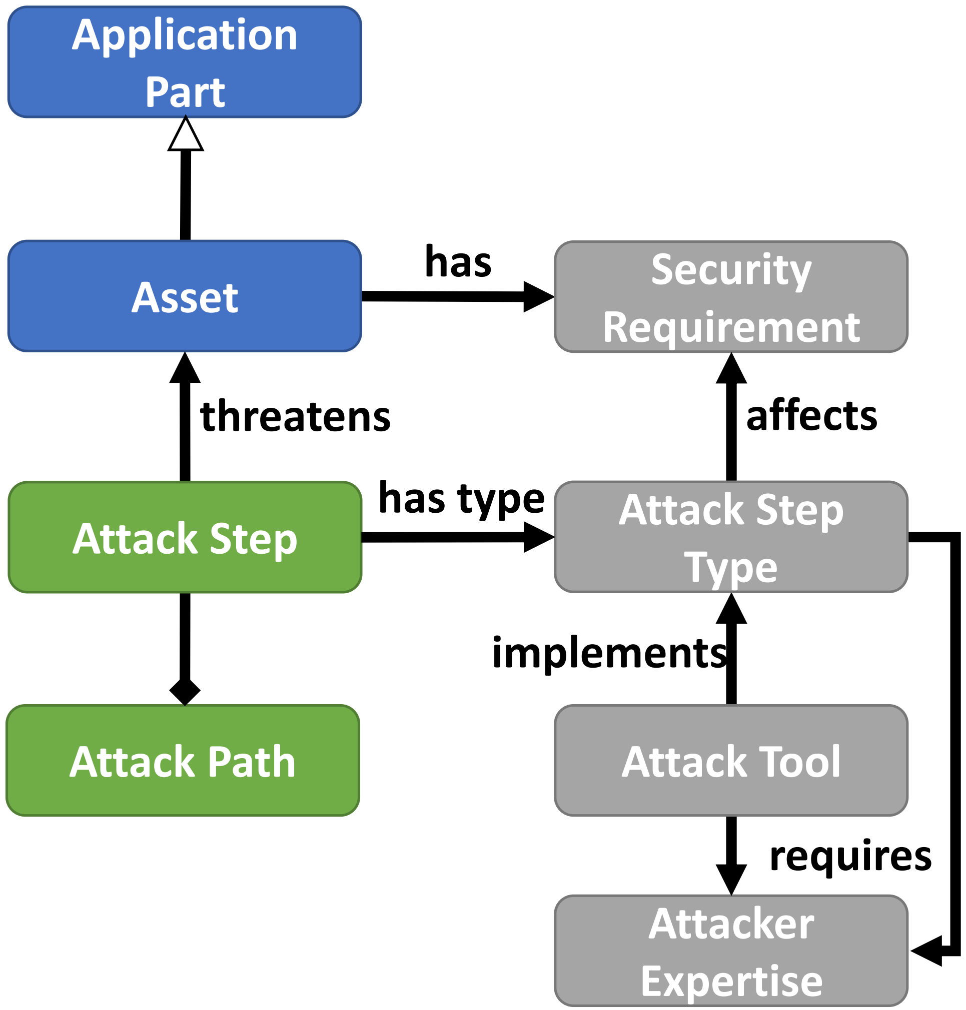


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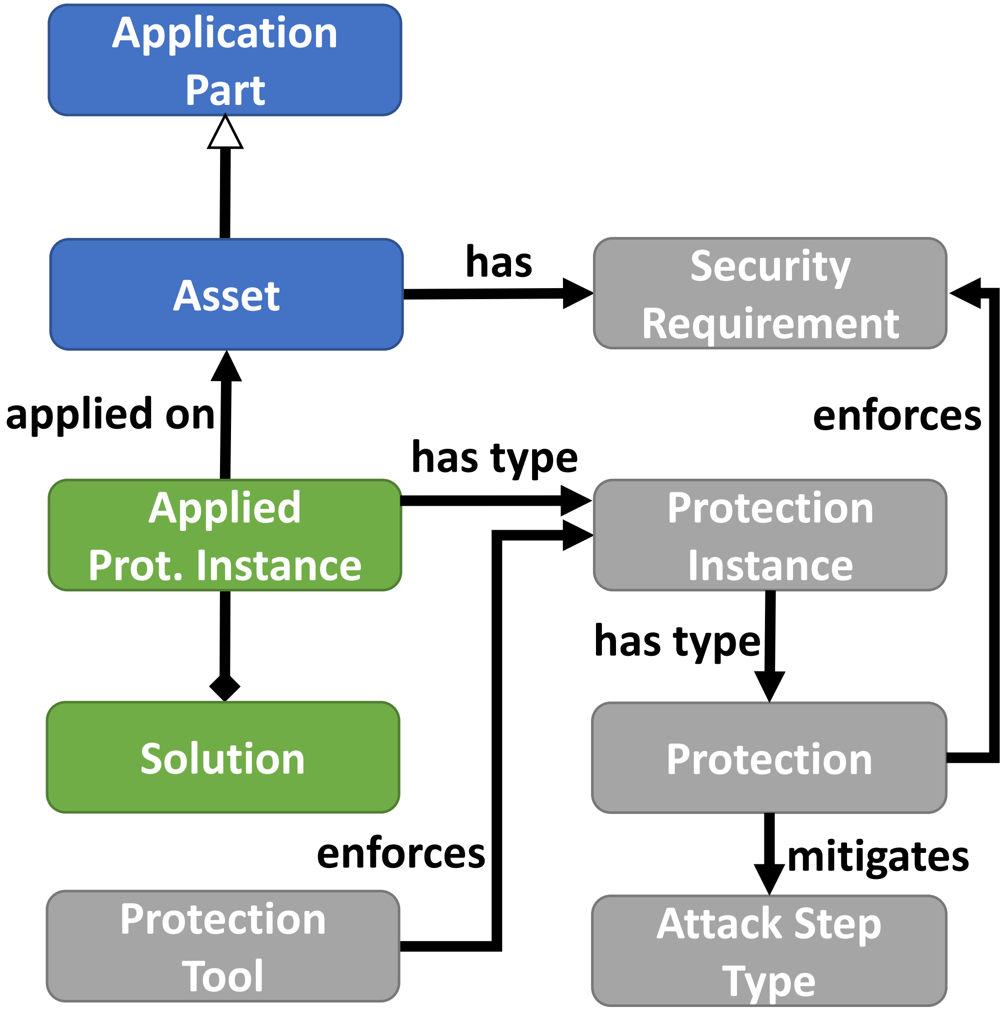


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# Risk assessment phase[5]

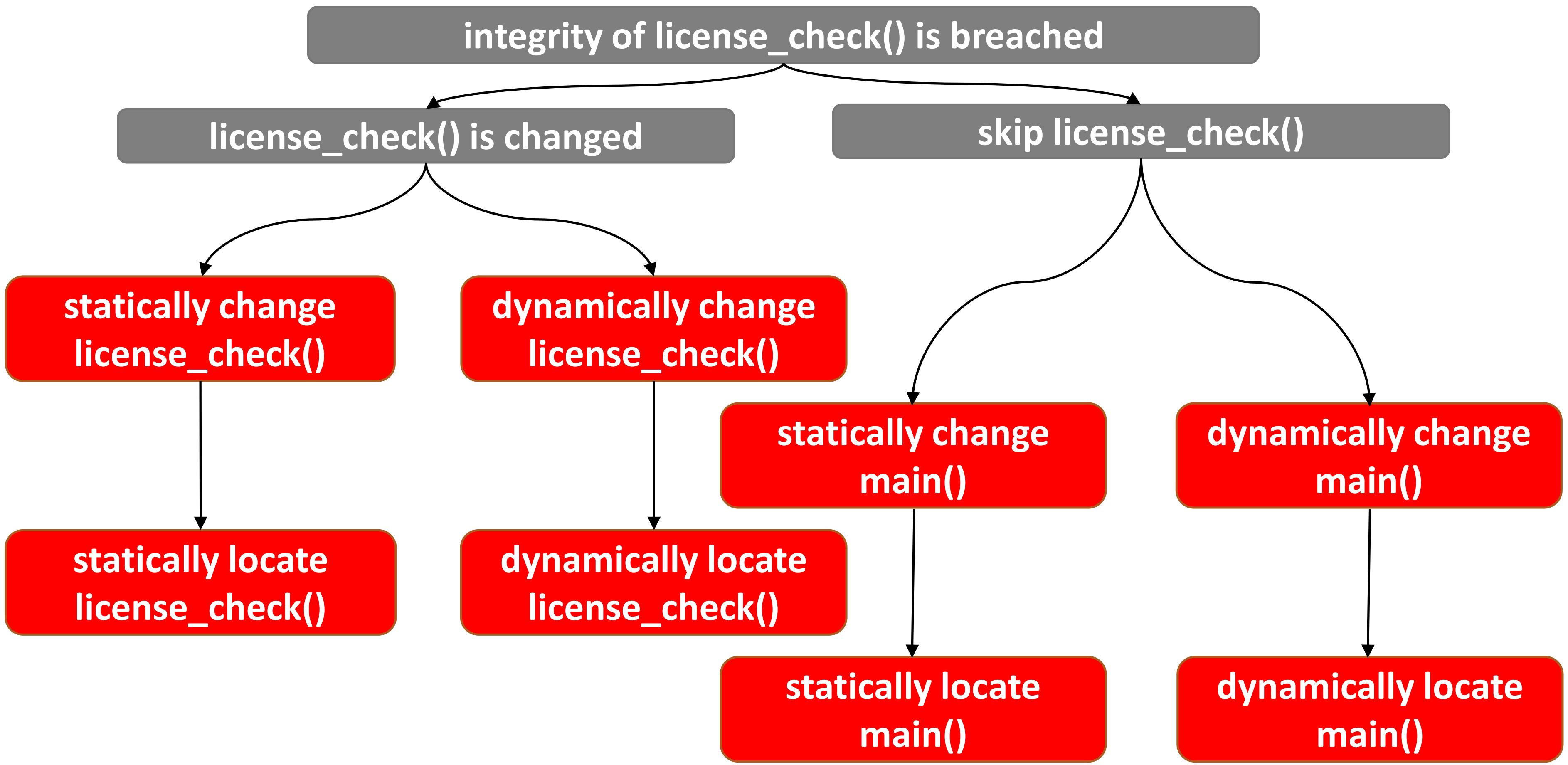
- infers possible attacks
  - on the unprotected application
  - able to breach assets' security requirements

- attack steps = simple attacker actions
  - expressed as Prolog inference rules

- attack paths = ordered sequences of attack steps
  - against actual assets

[5]L. Regano, D. Canavese, C. Basile, A. Viticchié, A. Lioy, Towards Automatic Risk Analysis and Mitigation of Software Applications, *2016 Workshop in Information Security Theory and Practice (WISTP)*, 2016

# Risk assessment phase: attack paths



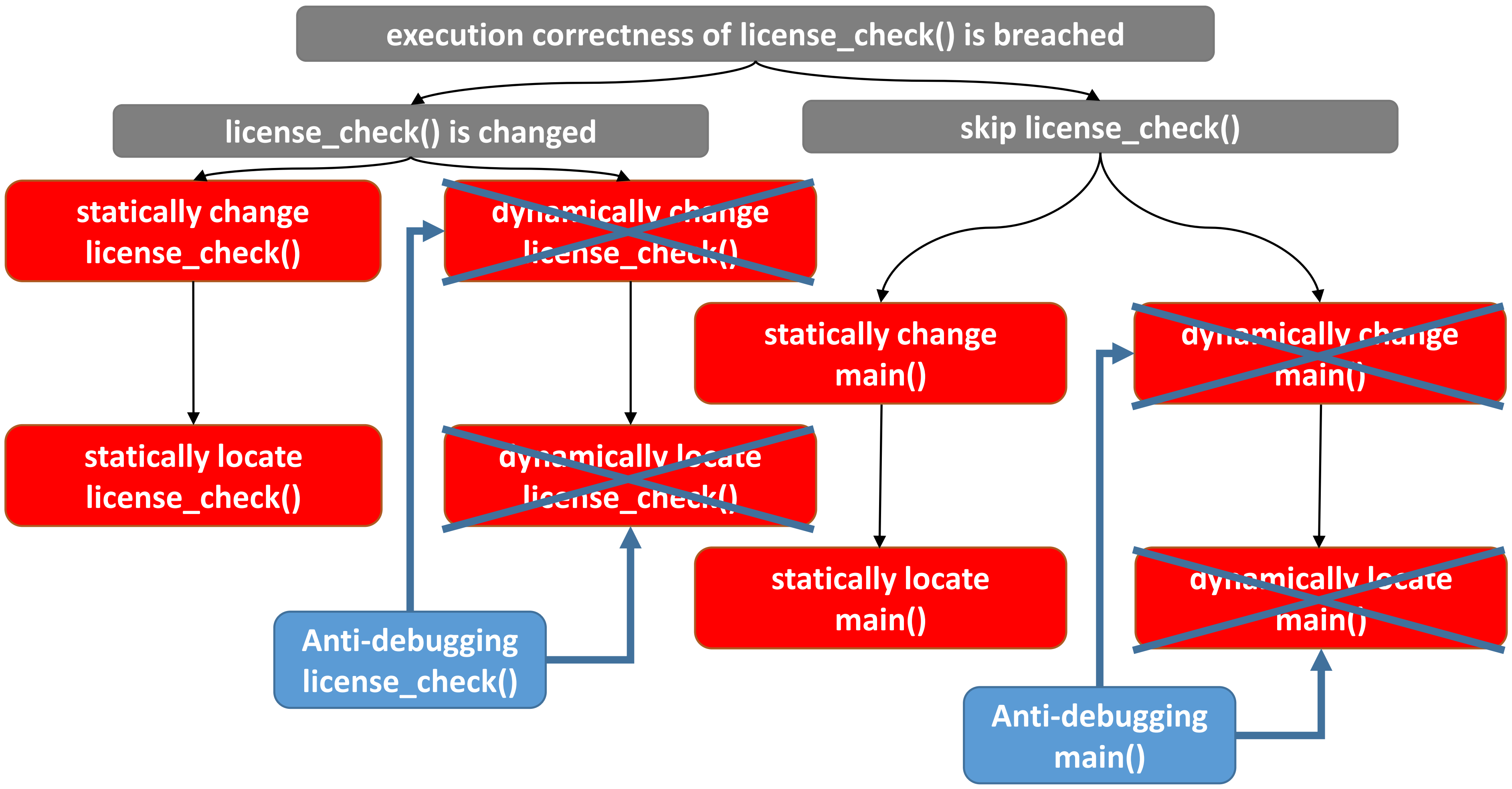
# Asset protection phase

- infers the optimal protection solution best able to defer attack paths

- takes into account:
  - structure of application
  - assets+security requirements
  - attack paths from risk assessment phase
  - interactions among protection techniques
  - protected application slow-down

- decision based on
  - experts knowledge
  - quantitative asset metrics (e.g. cyclomatic complexity)

# Asset protection phase: protections vs. attacks



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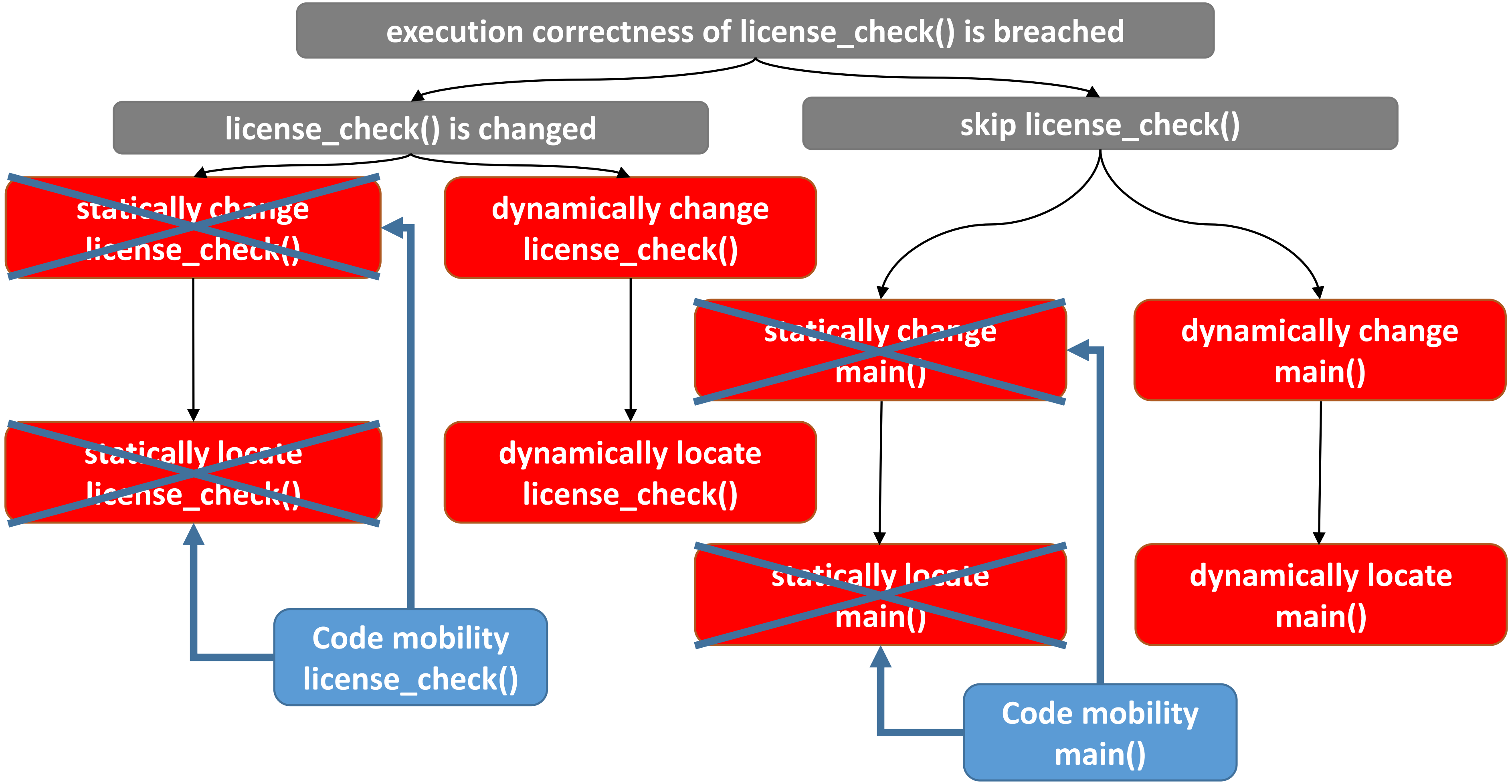

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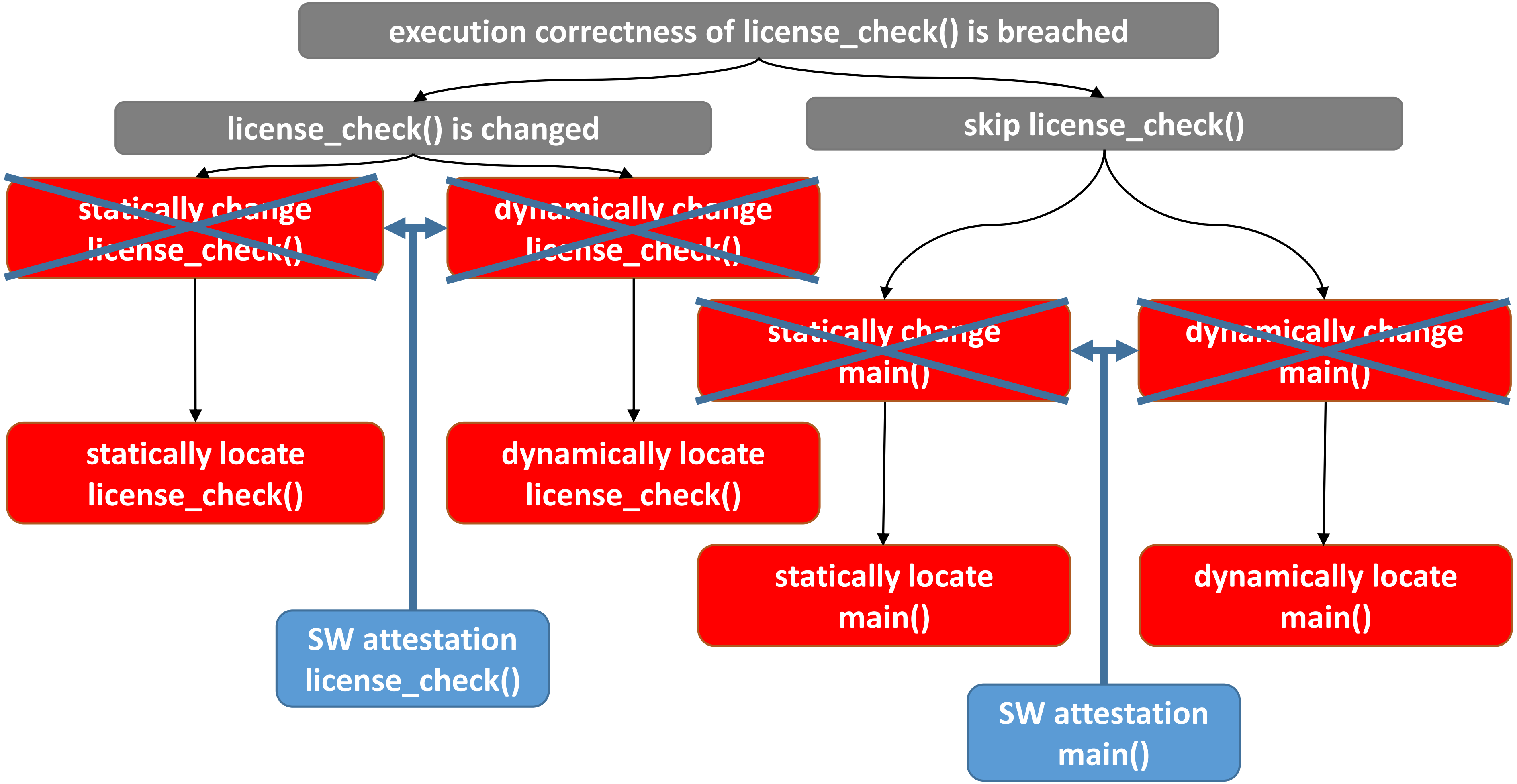
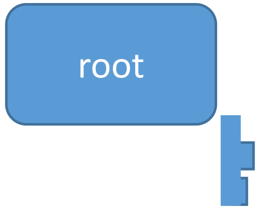


# Asset protection phase: valid protection solutions

- must be able to defer all attack paths
- business logic of the application must remain unaltered
- ordering among protections applied on the same asset is important
- protected application slow-down must be below user-defined limits

# Asset protection phase: game-theoretic approach

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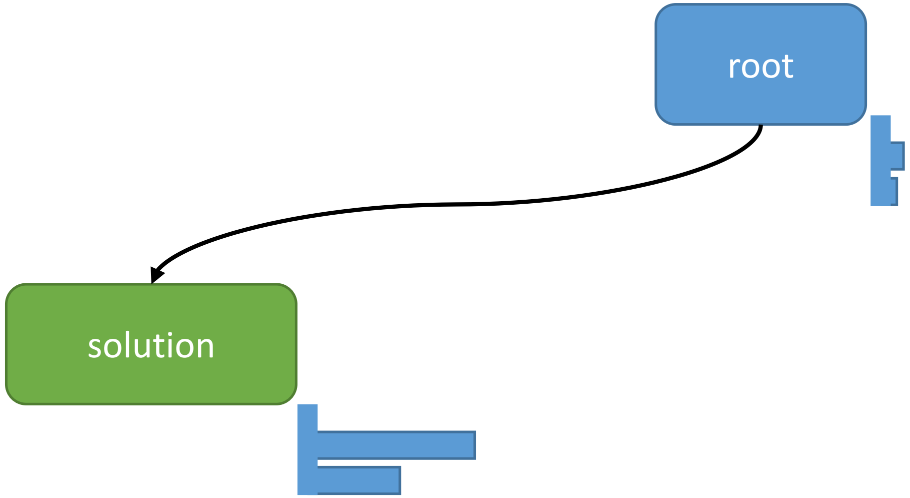


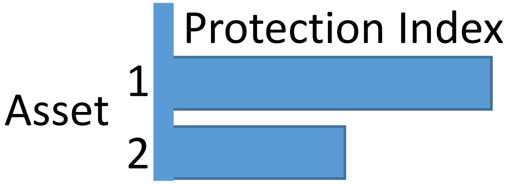

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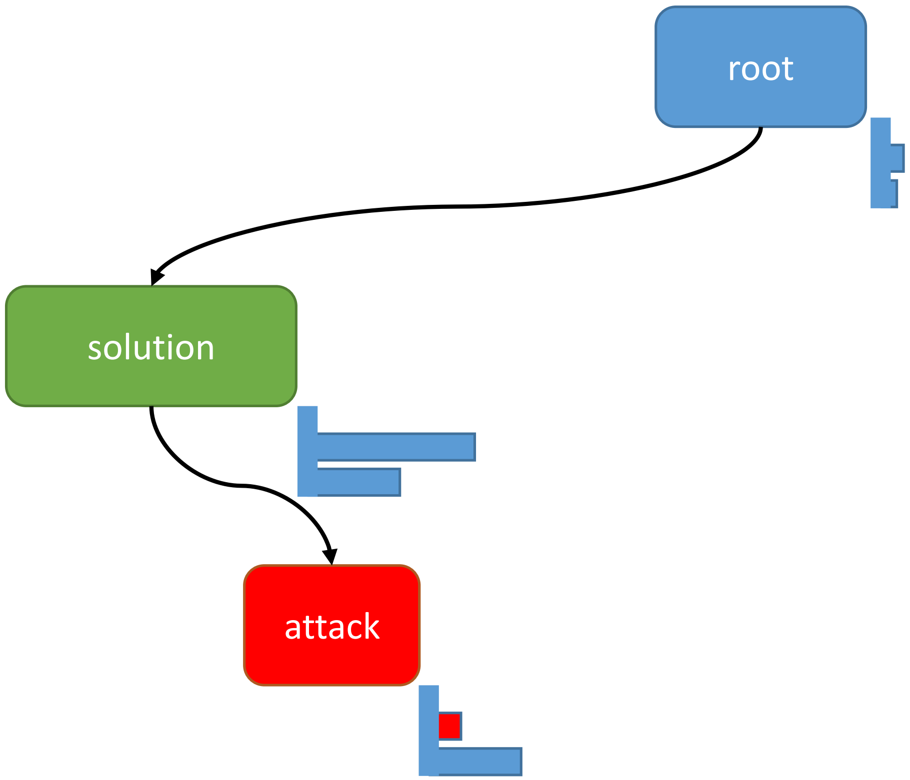


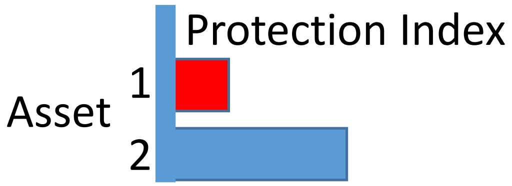

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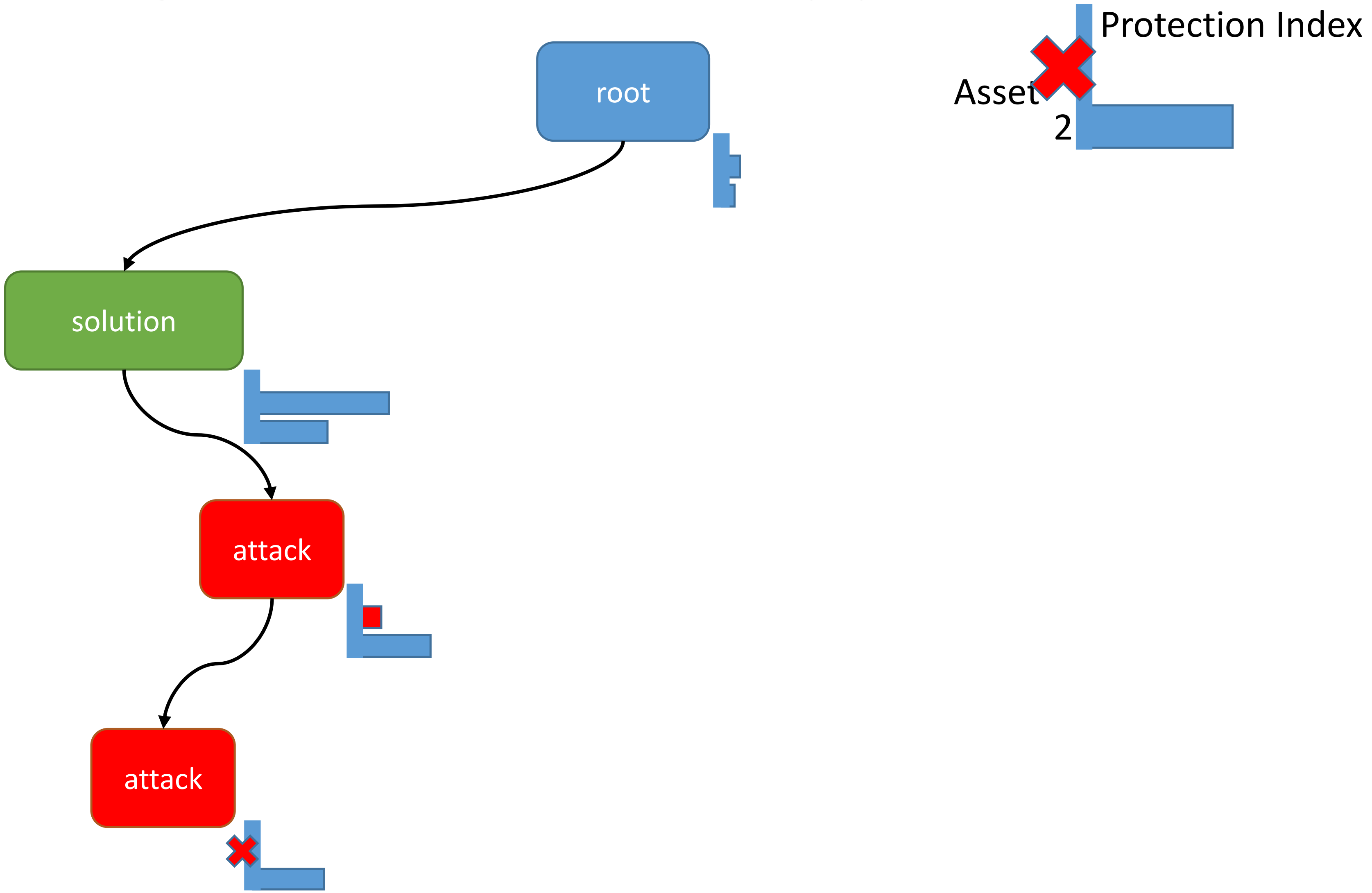

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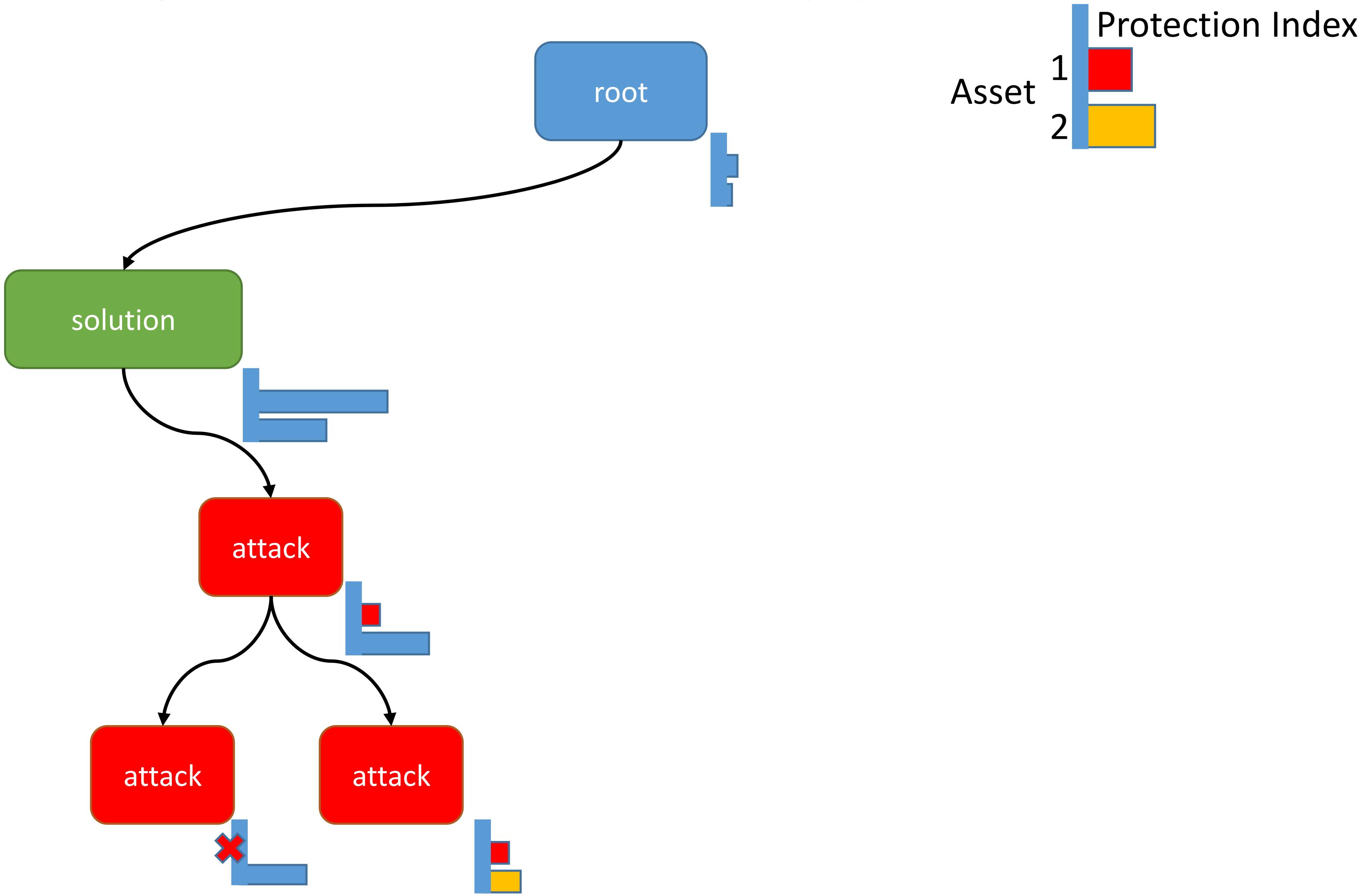

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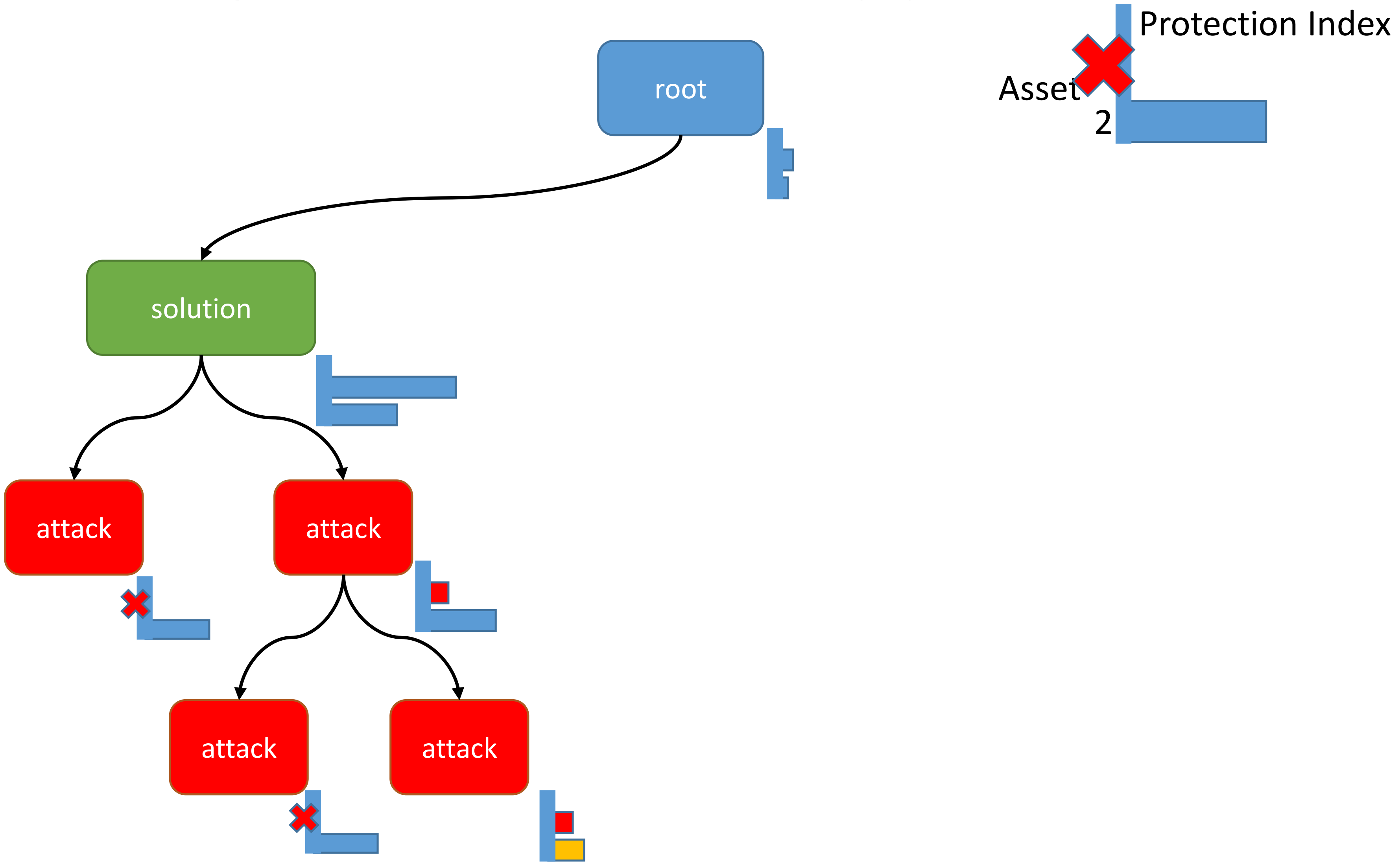

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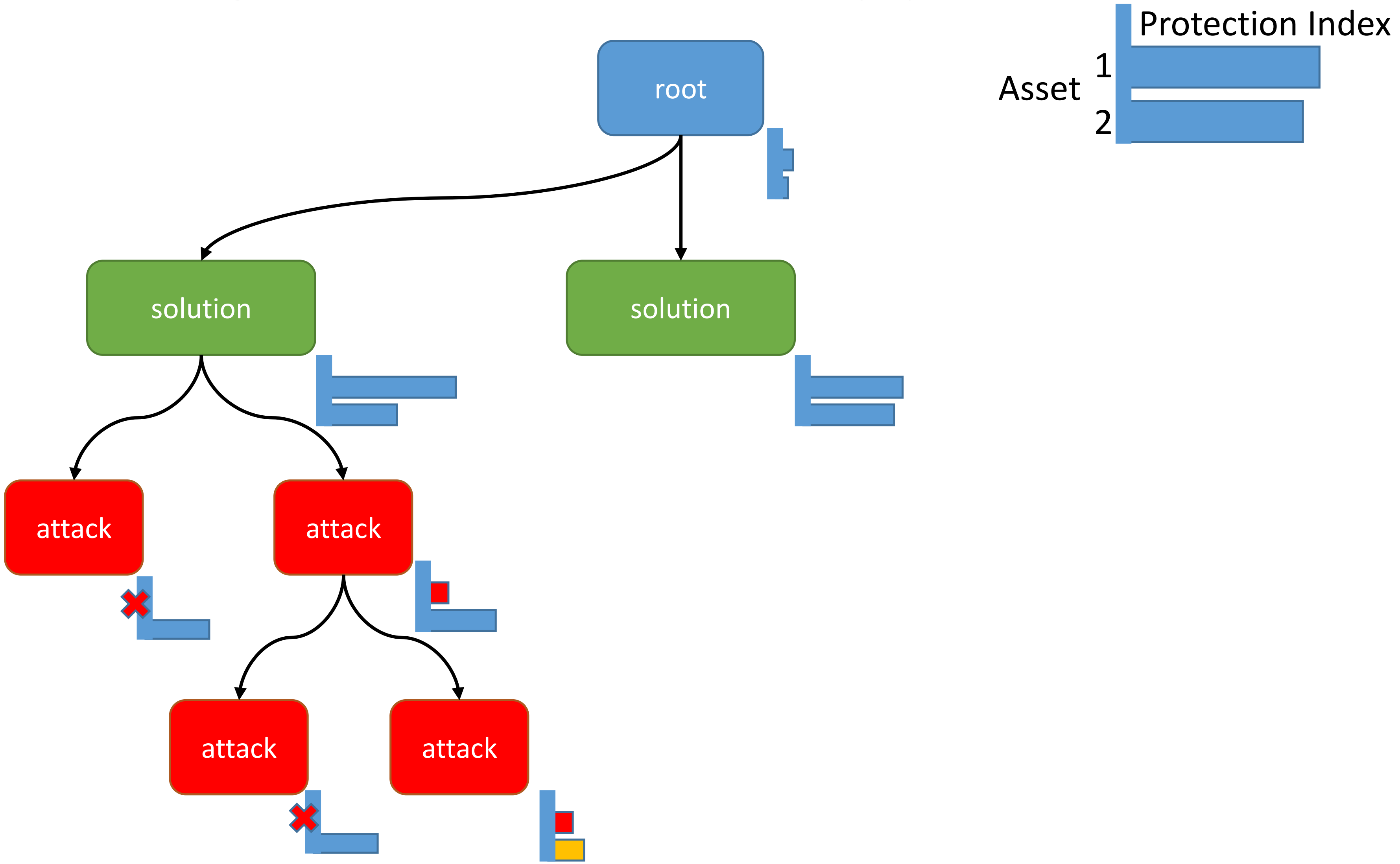

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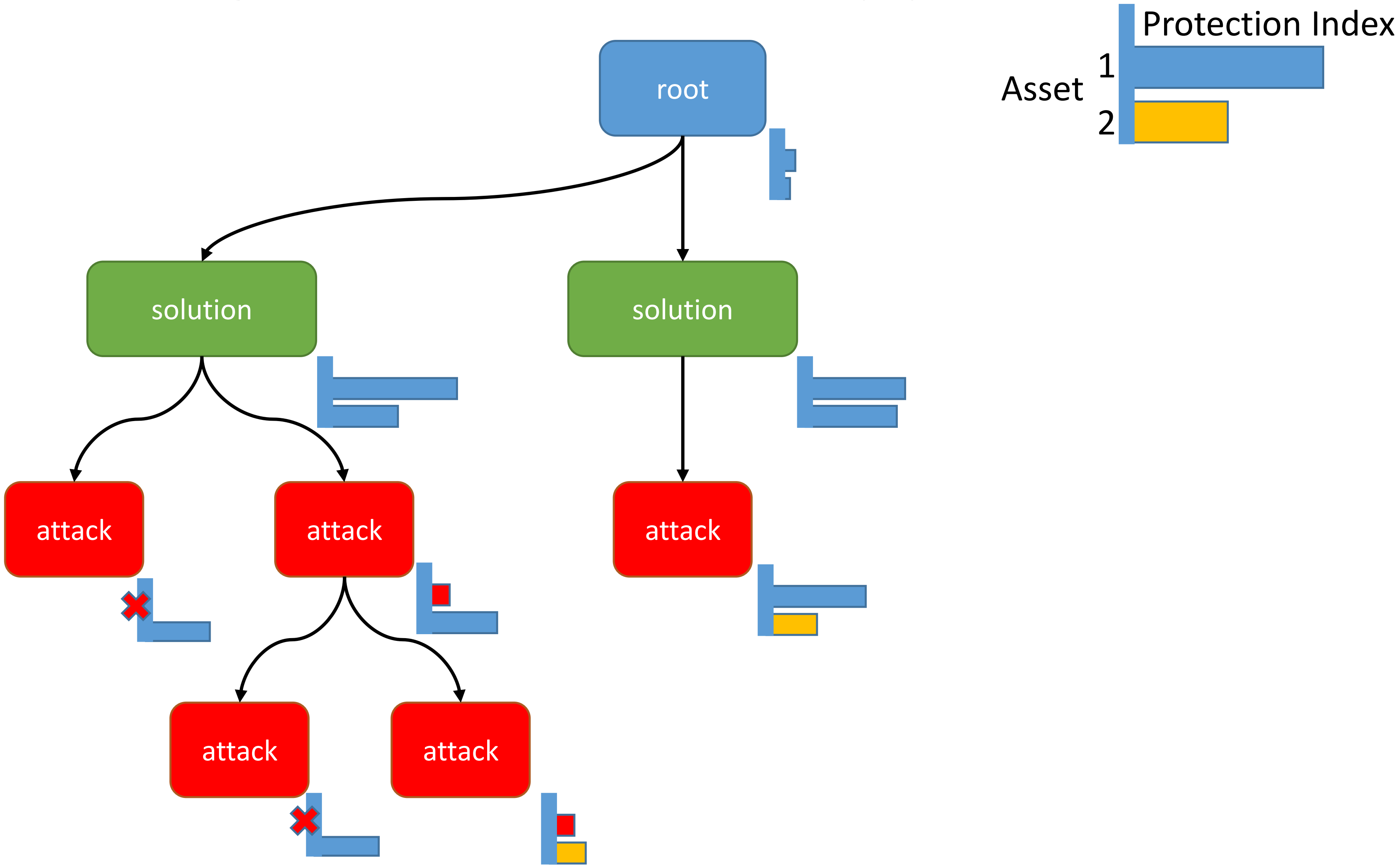

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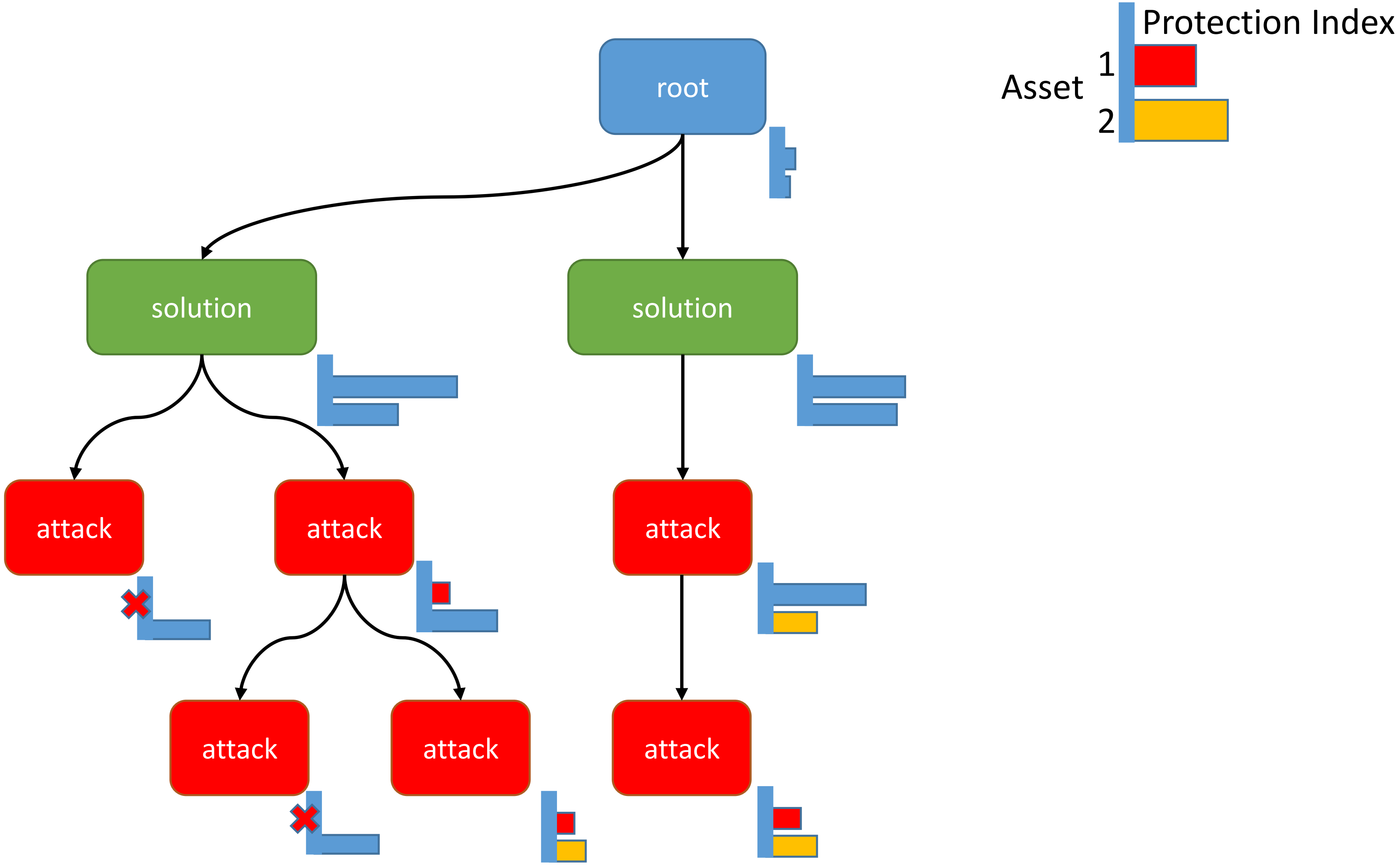

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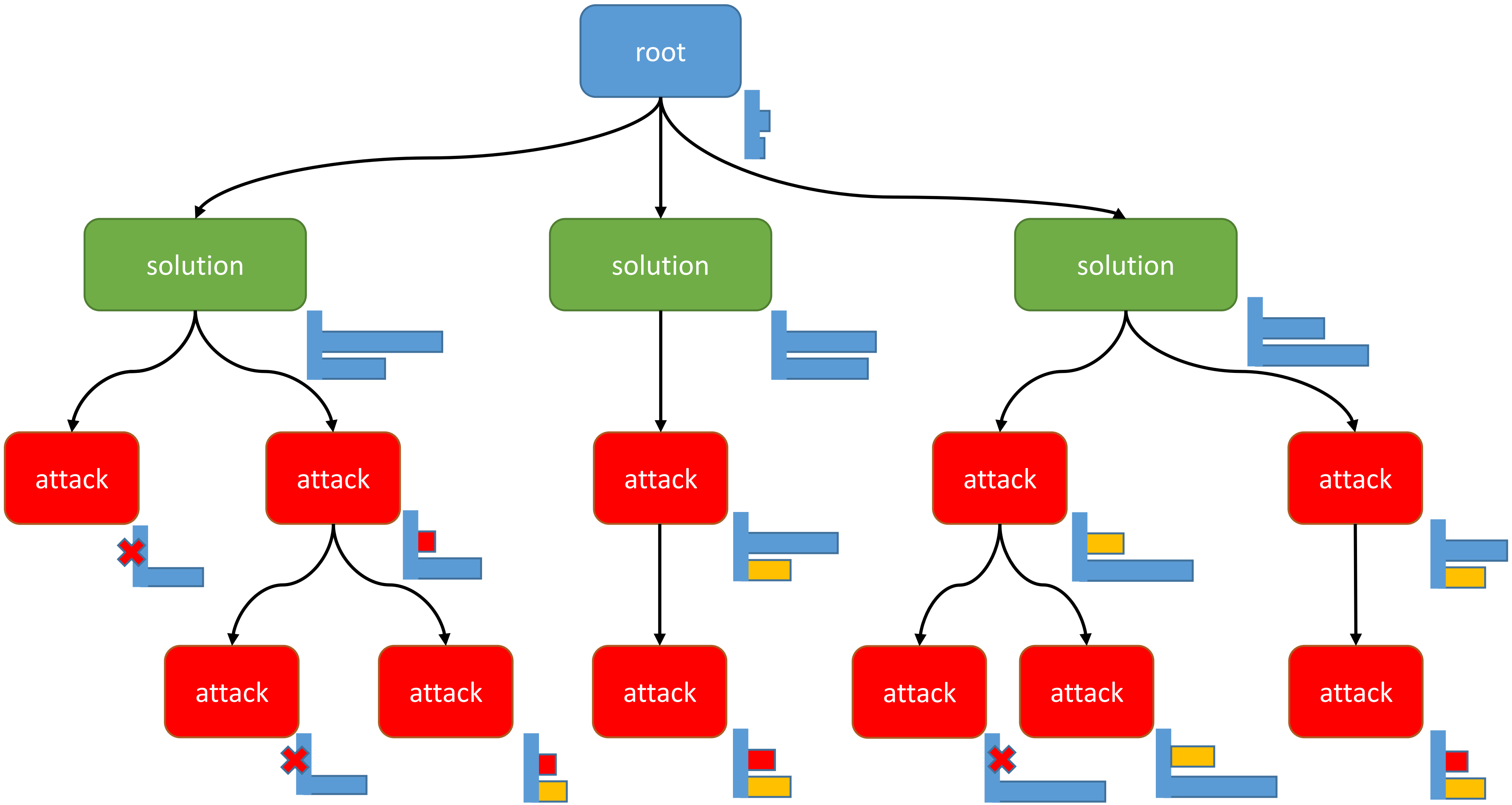

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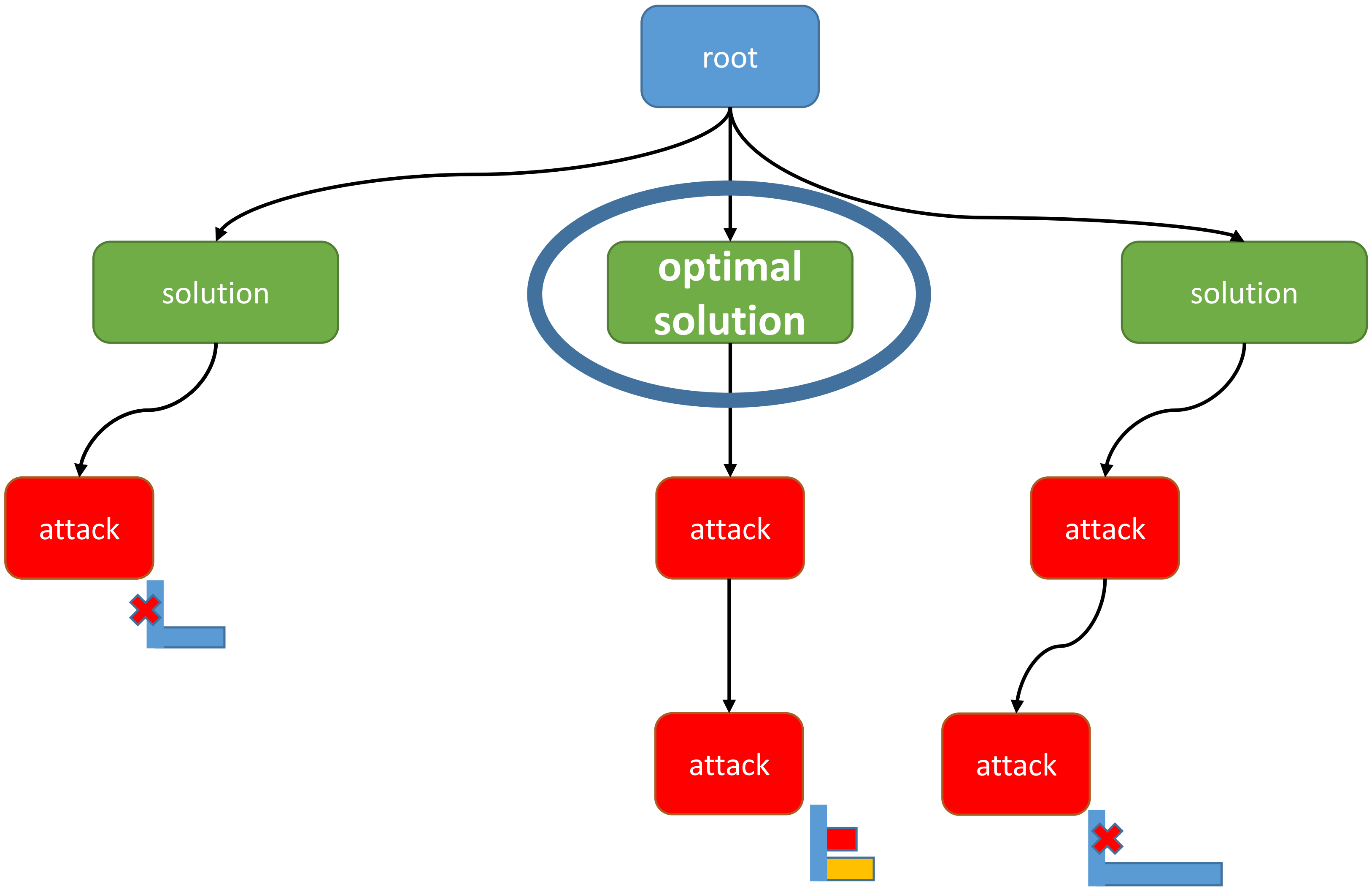


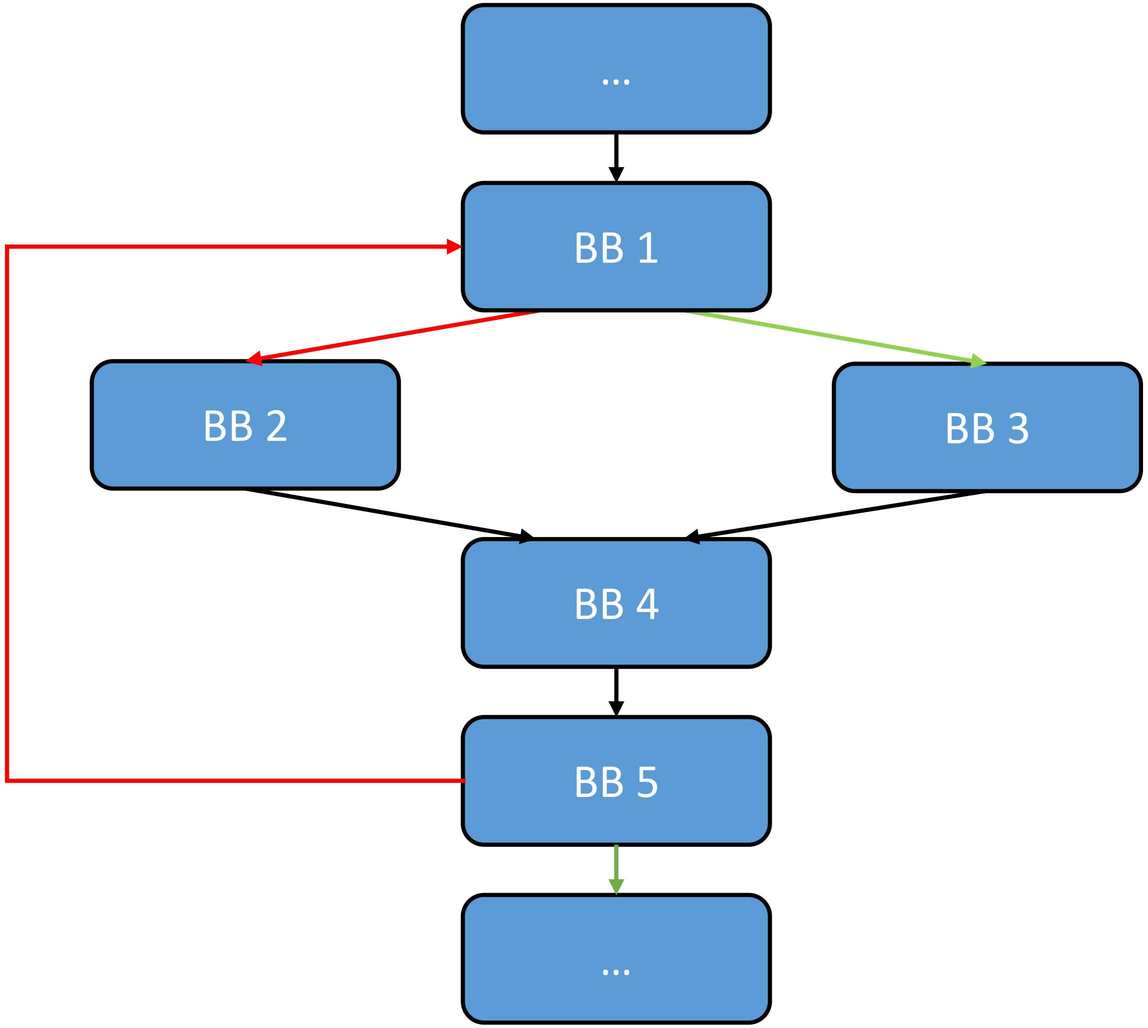
# Asset hiding phase[6]

- problem: software protections might expose a ''fingerprint''
  - fingerprints: code patterns, peculiar behaviors, etc.
  - attackers locate assets looking for protection fingerprints

- solution: Asset Hiding (AH) phase
  - apply protections to hide fingerprints
  - trade-off between fingerprint hiding and overhead
  - state of the art: manually obfuscate as much code as possible

[6]L. Regano, D. Canavese, C. Basile, A. Lioy, Towards Optimally Hiding Protected Assets in Software Applications, *2017 IEEE International Conference on Software Quality, Reliability and Security (QRS)*, 2017

# Fingerprint example:
## Control Flow Flattening



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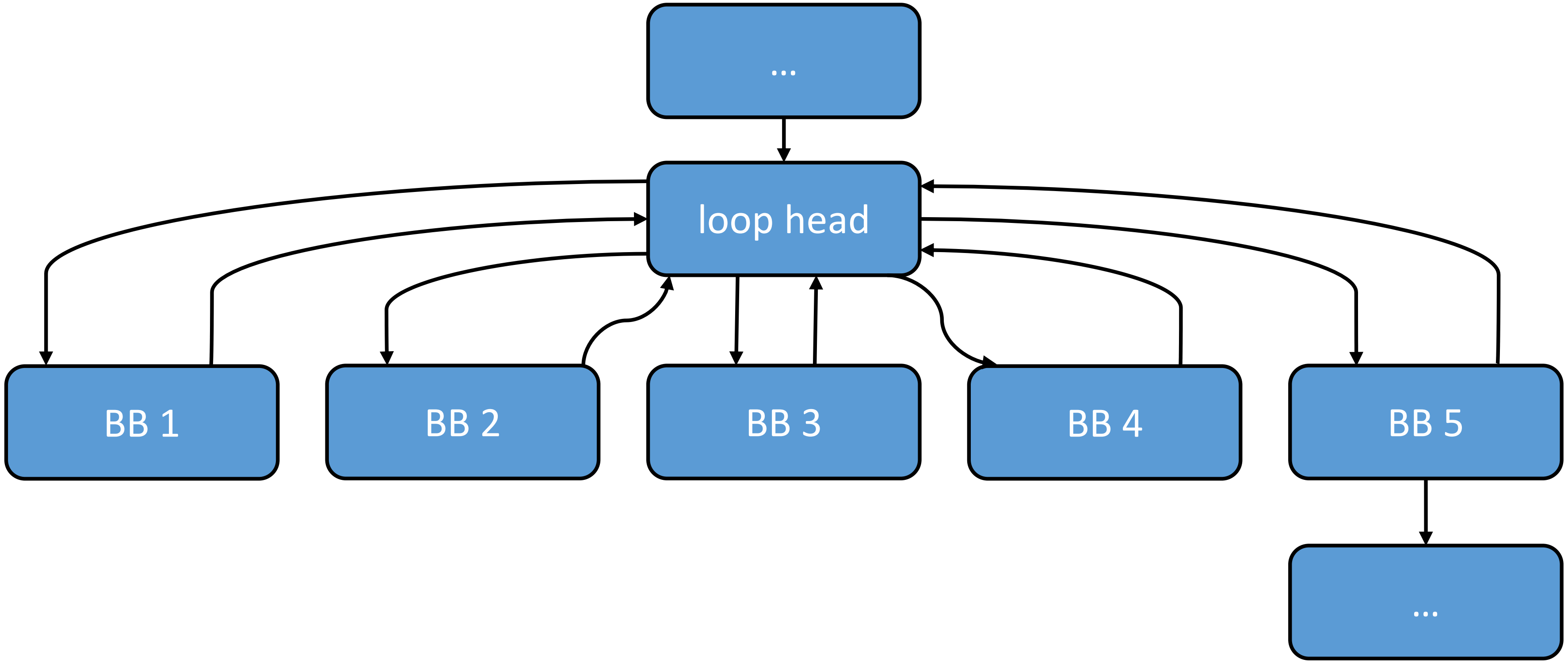

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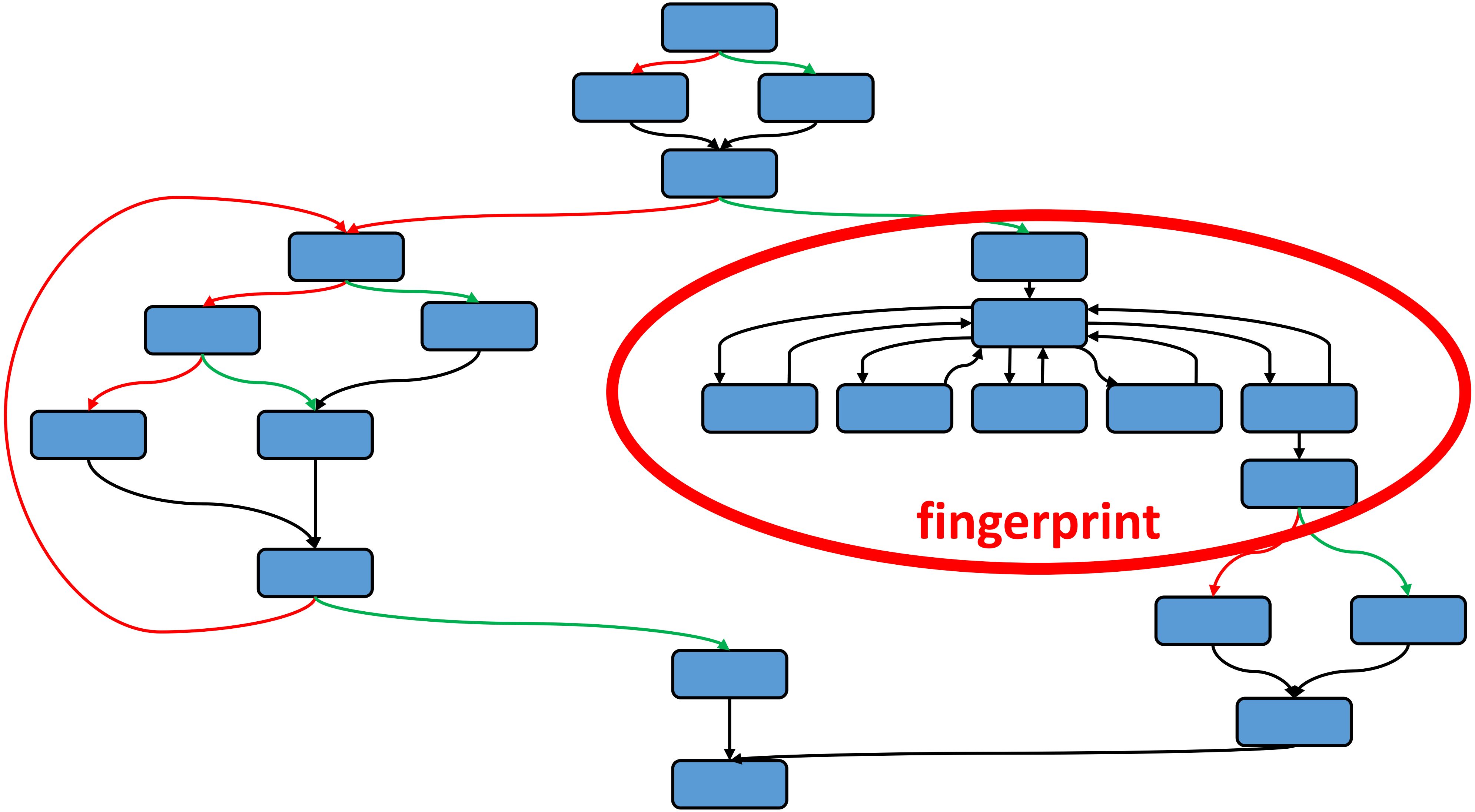
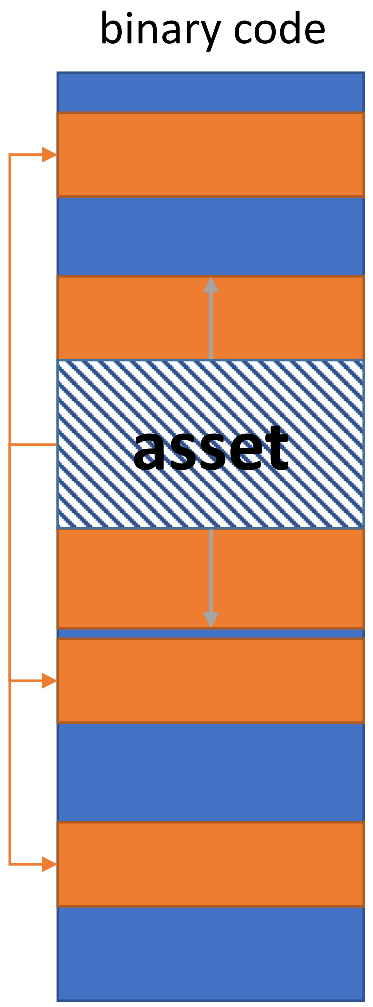


# Asset hiding phase: strategies

- Asset Hiding strategies:
  - fingerprint replication
  - protected area enlargement
  - fingerprint shadowing
- deciding AH protections is difficult:
  - not all strategies are useful to hide all protections
  - some strategies may lower AP protections security
  - overhead must be taken into account



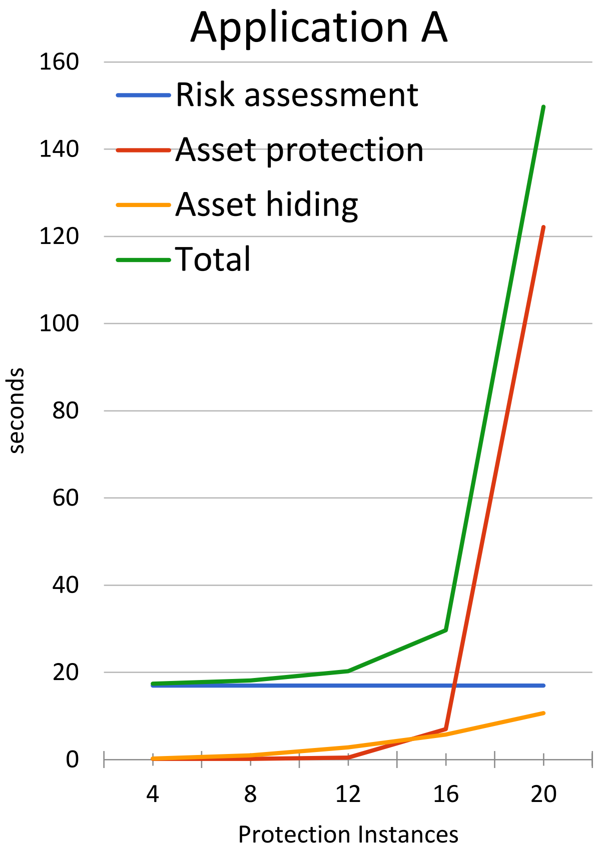
# Asset hiding phase: approach

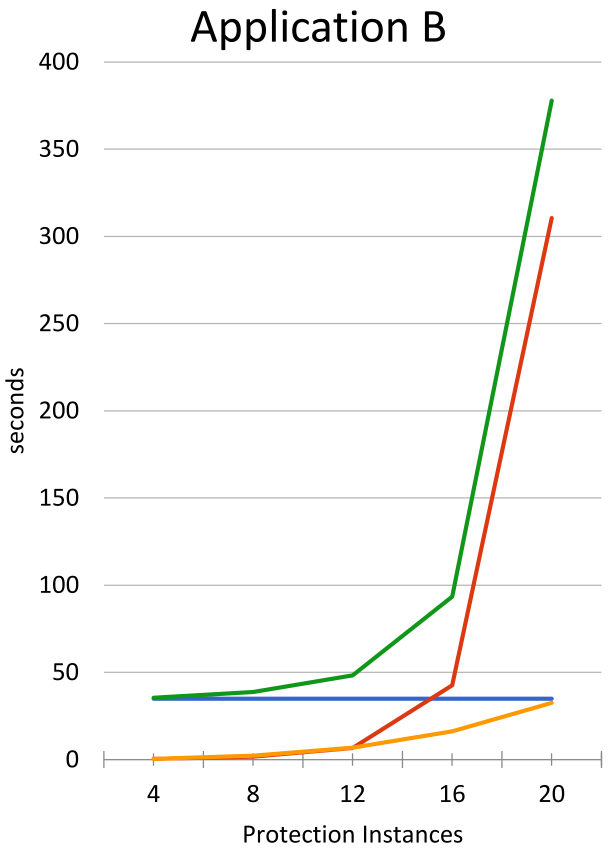
- objective: maximize the confusion index
  - confusion index: how much the attacker is expected do be delayed by the AH in finding the assets
  - applying an AH protection increases the confusion index
- custom Mixed Integer-Linear problem
  - based on the well-known Knapsack Problem
  - capacity constraints: overhead limits (e.g. CPU time, memory)

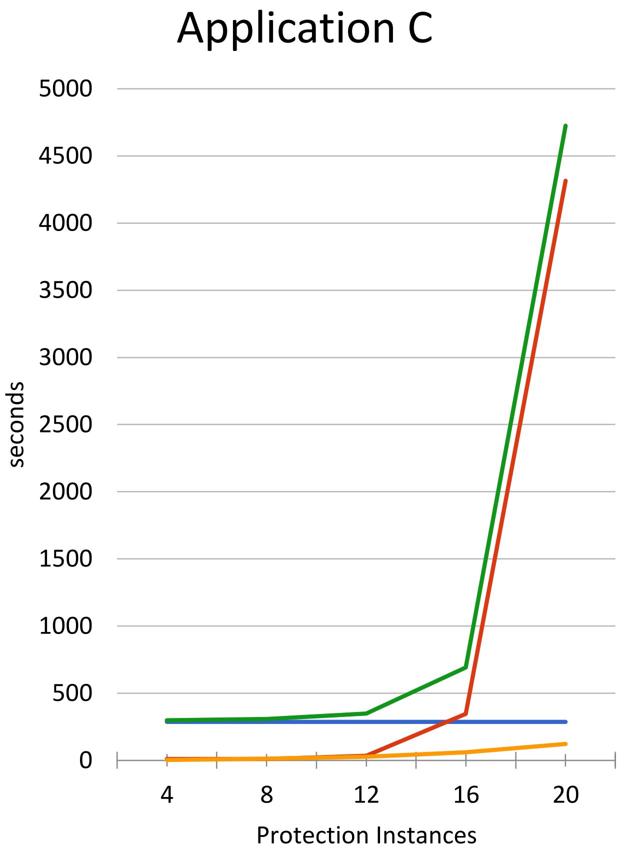
# Validation by experts

- ESP tested on three real-life use-cases
  - OTP generator, application licensing scheme, DRM video player
- ESP results validated by software security experts
  - attack paths cover real attacks by tiger teams
  - protection solutions effectively block attacks
  - protection solutions leave applications business logic unaltered
  - protection solutions introduce limited overhead

# Experimental results




| Application | SLOC | Functions | Assets |
|---|---|---|---|
| A | 443 | 18 | 4 |
| B | 1029 | 47 | 15 |
| C | 3749 | 178 | 39 |

# Conclusions and future work

- completely automated workflow for software protection
  - user must only identify assets and security requirements
  - infers attacks against assets
  - decides best protection to defer attacks
  - deploys protections by driving automatic protection tools

- results validated by software security experts

- future work: empirical assessment of software protections
  - master students asked to attack protected applications…
  - …to assess how much attackers are deferred by protections
  - useful data to drive ESP reasoning processes

Thank you
for your attention!

Questions?