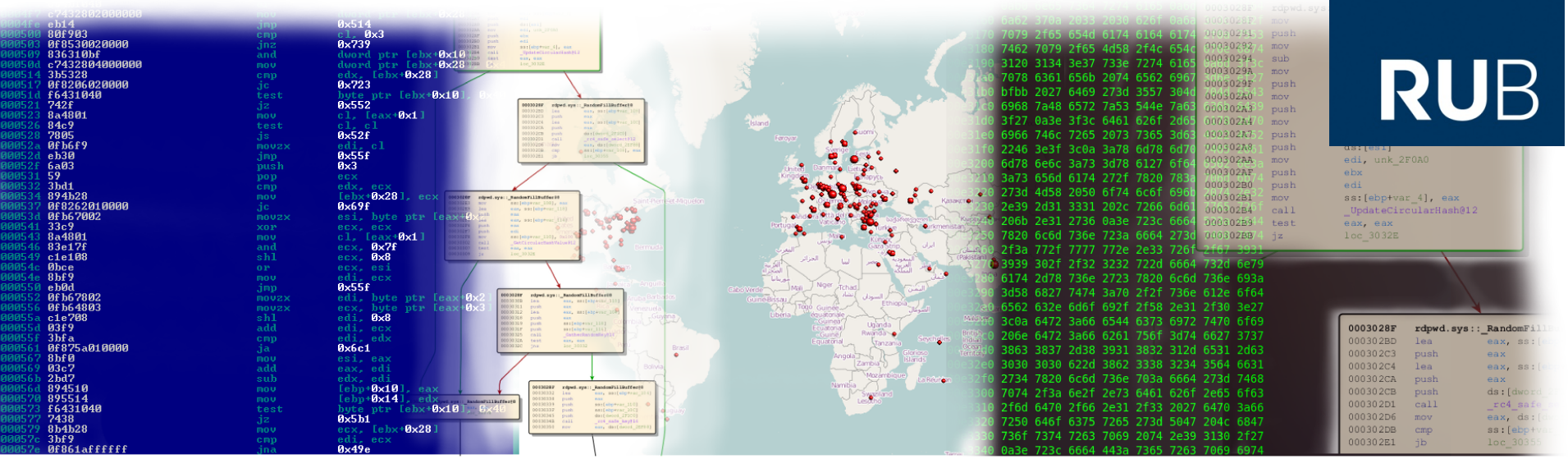

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Leveraging Semantic Signatures for Bug Search in Binary Programs

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TEDEM - Pinpoint Vulnerabilities

Tree-Edit-Distance-based Equational Matching

- You show us a bug in a binary
- We re-find that bug in (another) binary

The basic assumption

- We know what a bug-instance looks like
- We find a piece of code, which looks very similar
- Likely, it contains the same bug

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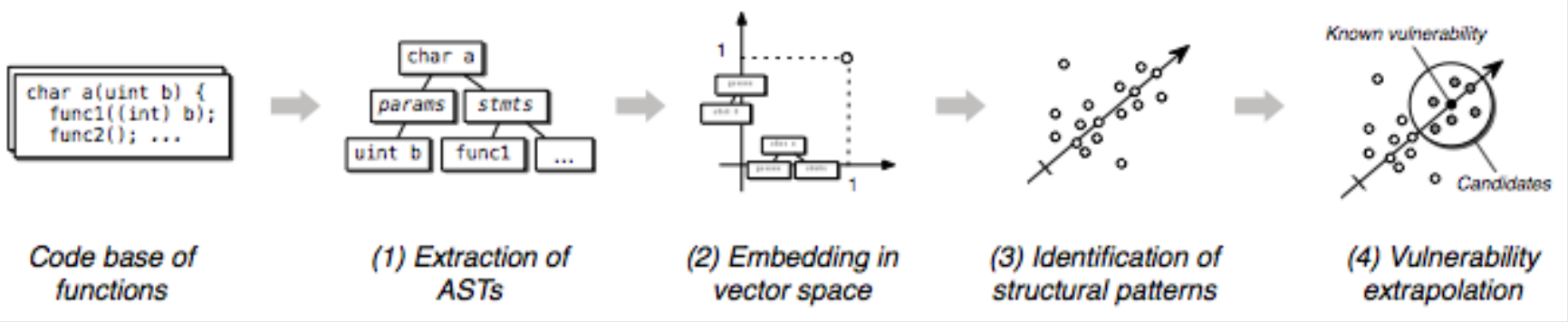
Tree-Edit-Distance-based Equational Matching

- Inspired by: Generalized Vulnerability Extrapolation using Abstract Syntax Trees (ACSAC 2012)
- Fabian Yamaguchi, Markus Lottmann, Konrad Rieck
- Analyse source code, embed AST into vector space
- Pick a bug, use metric of that space to find similar code vectors



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What we want

- Bug instances instead of bug classes
- Nearest neighbors instead of clustering
- Binary instead of source code
  - otherwise: cross-binary is hard
- Respect semantics/structure (rather than synthax)
- Sub-function granularity
- Focus on bug-relevant parts

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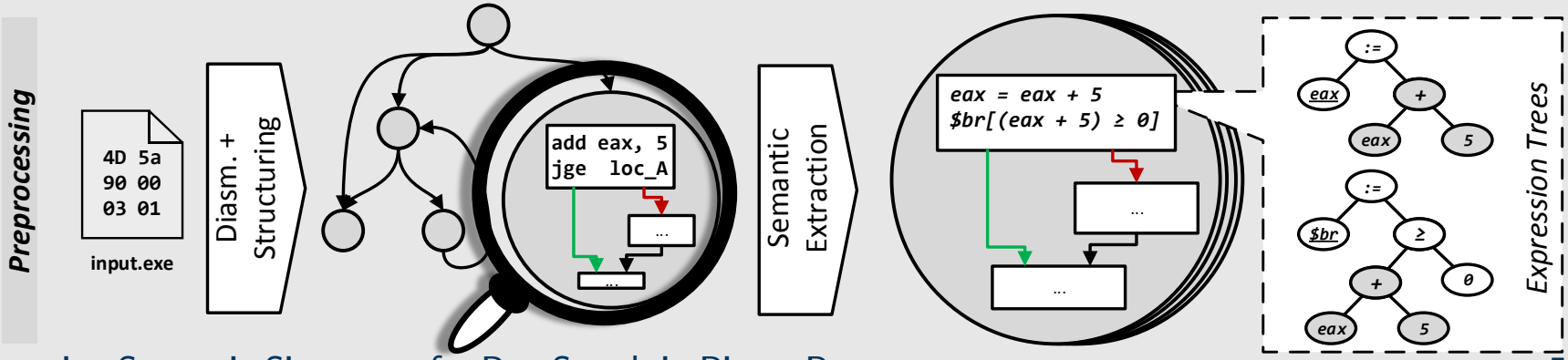
Preprocessing

- Analyze the binary (Disassembly, Basic Blocks, CFG)
- *Real* Basic Blocks: Split at calls
- BB: Input-State $\mapsto$ Output-State
  - Aggregates and normalizes "Effect of BB on state"
  - Data-Structure: Tree
- Signature (what we search): CFG of BB-Input/Output-Equations
- Target (*in* what we search): CFG of BB-Input/Output-Equations



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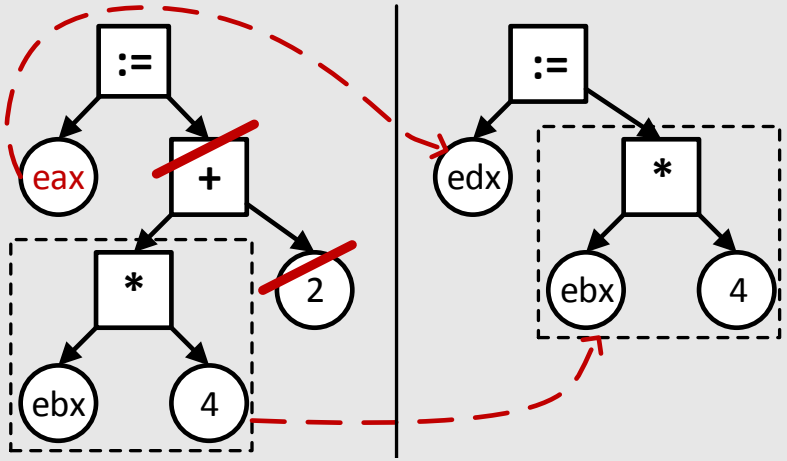
Tree Edit Distance

- Basic Blocks are now essentially trees
- DISCLAIMER: No fully semantic comparison
  - But: Syntactic comparison, based on condensed, abstracted and normalized semantics
- Efficient XML Structural Similarity Detection using Sub-tree Commonalities (SBBD 2007)
- Tekli, Chbeir, Yetongnon



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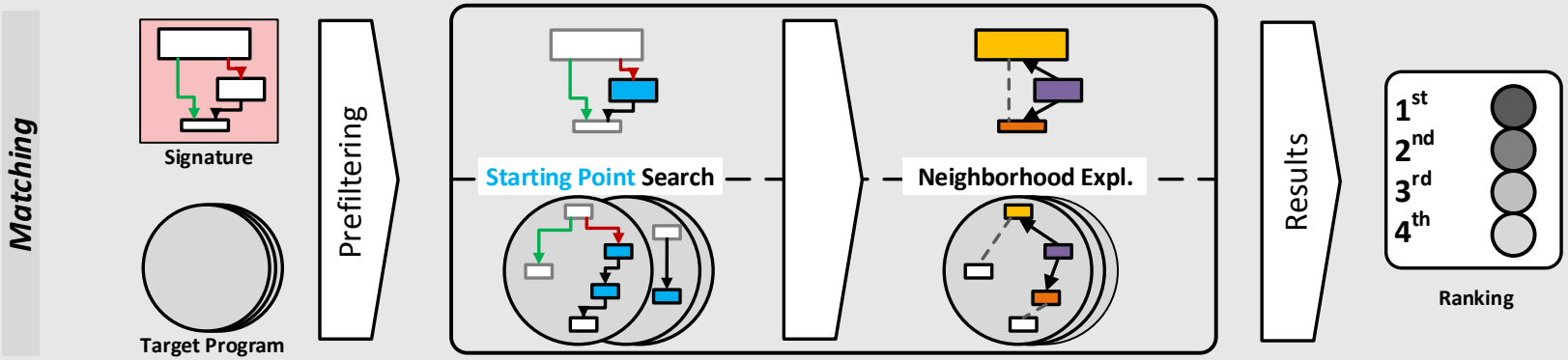
Matching

- $\forall$ BB $\in$ Signature: Find BB-level starting points in target
  - Prefilter: Use heuristics; e.g. tree-size
  - Tree-Edit-Distance (with subtree edits)
- $\forall$ starting points:

  Explore Neighborhood, broaden match along next-best candidate in CFG, until full signature is matched
  - Greedy, but locally optimal
- Sort by overall distance $\Rightarrow$ Ranking



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Our niche: Fine-grained binary code comparison for bug-finding

- Usually: Search for bigger units (i.e. whole functions/libraries)
- Usually: Less precise metric, rely on "statistic effects"

Results

- Pretty realiable for
  - Forks (ImageMagick/GraphixMagick, putty/tutty/puttycyg)
  - Shared Codebase (Pidgin/Adium;
    MS Word/Wordviewer/Compatibility Pack)
  - Multiple bug-occurrences in the same program
    - Results comparable to Yamaguchi's work *on source code*
- Sometimes even across OS-/compiler-borders
- Ironically, sometimes better than our manual ground-truth

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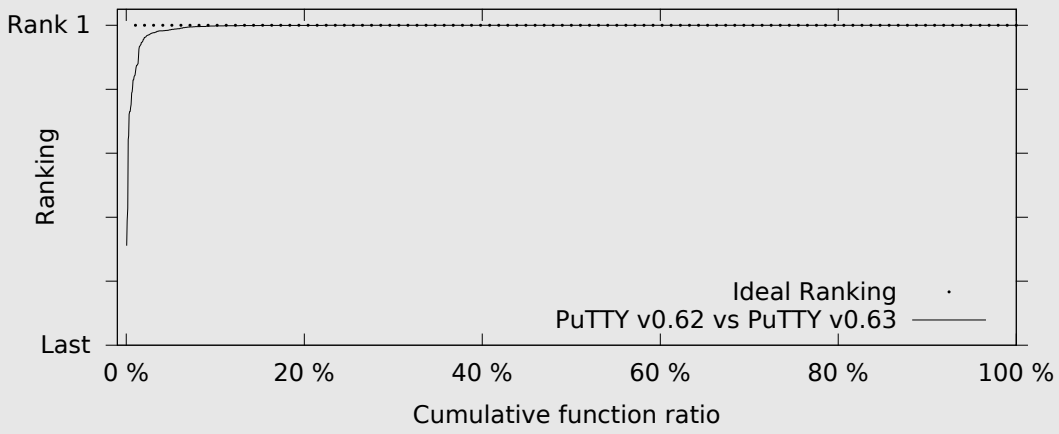
Experiments

- Our use-case $\neq$ function-matching
- No weighting
  - ... of bug-relevant/-irrelevant (Neighborhood Exploration)
  - ... of boilerplate-change vs. relevant change (Tree Edit Distance)
- No symbols, except to establish ground-truth
- On as-found-in-the-wild binary code; up to 400,000 BBs



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Runtime

- Preprocessing: One-time effort
  - Linear in |Program|
- Search for starting points
  - Linear in |Signature|
  - Linear in |Target| (Reduced to 5-10% with prefiltering)
  - Dominates runtime
- Tree Edit Distance
  - Quadratic in |Nodes|
- Neighborhood Exploration
  - Linear in |Signature|
  - Linear in #Neighbors of matched BBs

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Extrapolation

- Metric shows a degree of deviation
- Equal $\neq$ similar
- We can not only find identical bugs, but similar bugs

True positive?

- We find similar code. Is it really a bug?
- Would require much more complex analysis
- Example: Patched Code

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Patched Code

- Patched code is standard case of false positive
- Use two signatures:
  - one for the unpatched code
  - one for the patched code
- Higher similarity to patched signature

$\Rightarrow$ Likely also patched

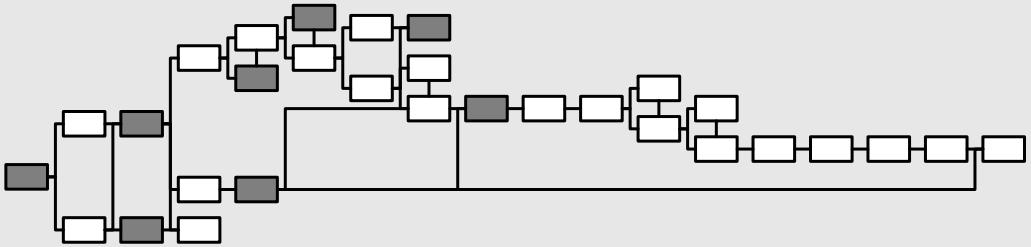
- Higher similarity to unpatched signature

$\Rightarrow$ Likely also unpatched

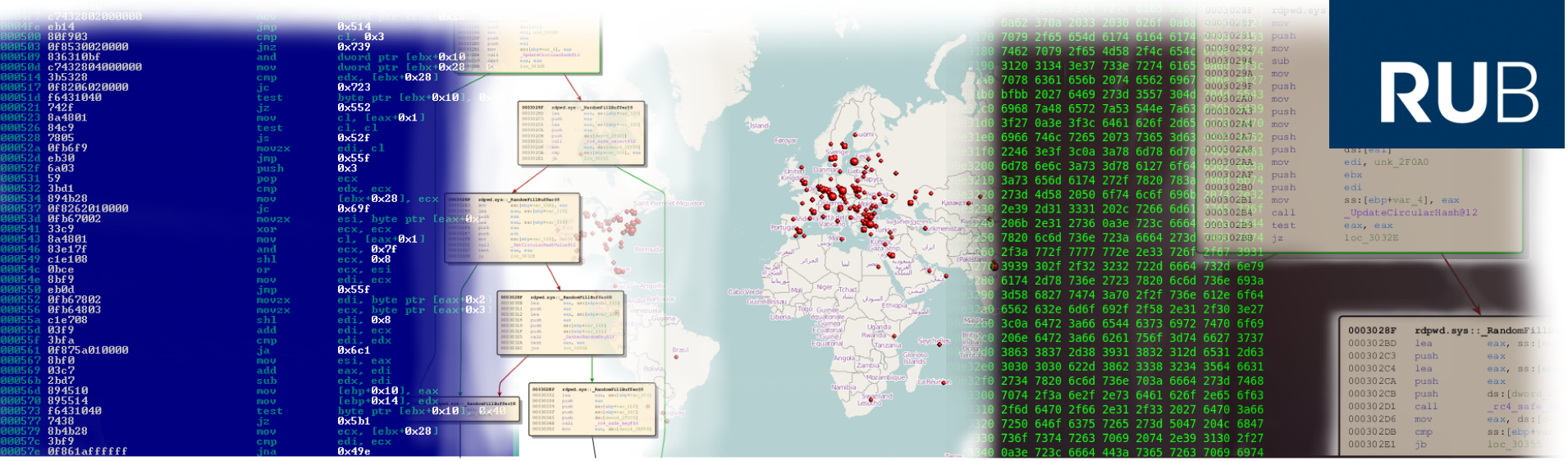
Limitations

Lessons learned

- Search for starting points dominates runtime
  - KD-Tree, VP-Tree, M-Tree did not work
- Neighborhood-relation needs to hold
  - Gaps or Recursive neighborhood exploration slow
- Based on similarity ⇒ Deviation affects results
  - Compiler, Optimization, Environment, ...



Good BB-matches in the two functions vulnerable to the Aurora-Bug



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Many thanks for your attention!

Questions?

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