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Department of Computer Sciences

Using Data-flow Analysis to Improve the Scalability of Model Checking

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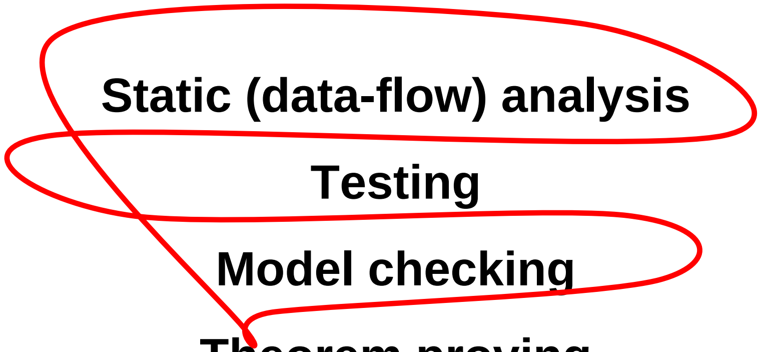
Project Goal

Unification of Verification and Validation Methods


Static (data-flow) analysis

Testing

Model checking

Theorem proving

Runtime Verification

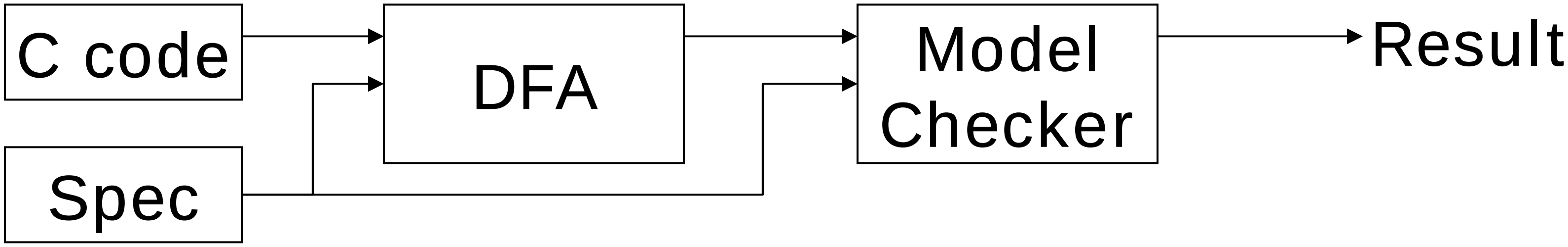
Model checking in one slide

- Method for proving properties of systems
- Suffers from state-space explosion
  - State-space grows exponentially
  - Does not scale for large software systems
- How do you reduce the state-space?

Use data-flow analysis (DFA)

□ Less precise but more efficient method for proving properties

□ We use DFA to improve model checking



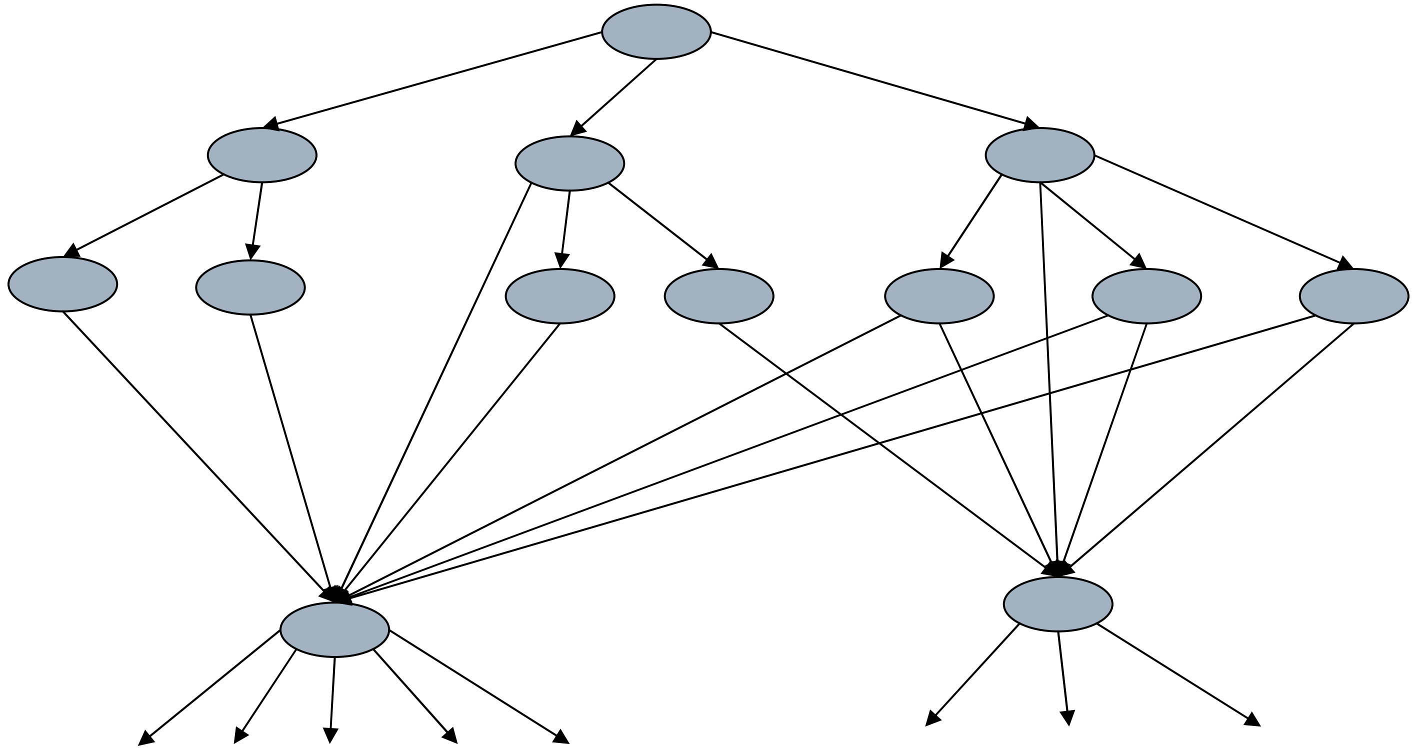
Improving model checking with DFA

- DFA has a number of approximation techniques
  - Context-insensitive analysis
  - Flow-insensitive analysis
  - Path-insensitive analysis
- Approximations improve performance of an analysis

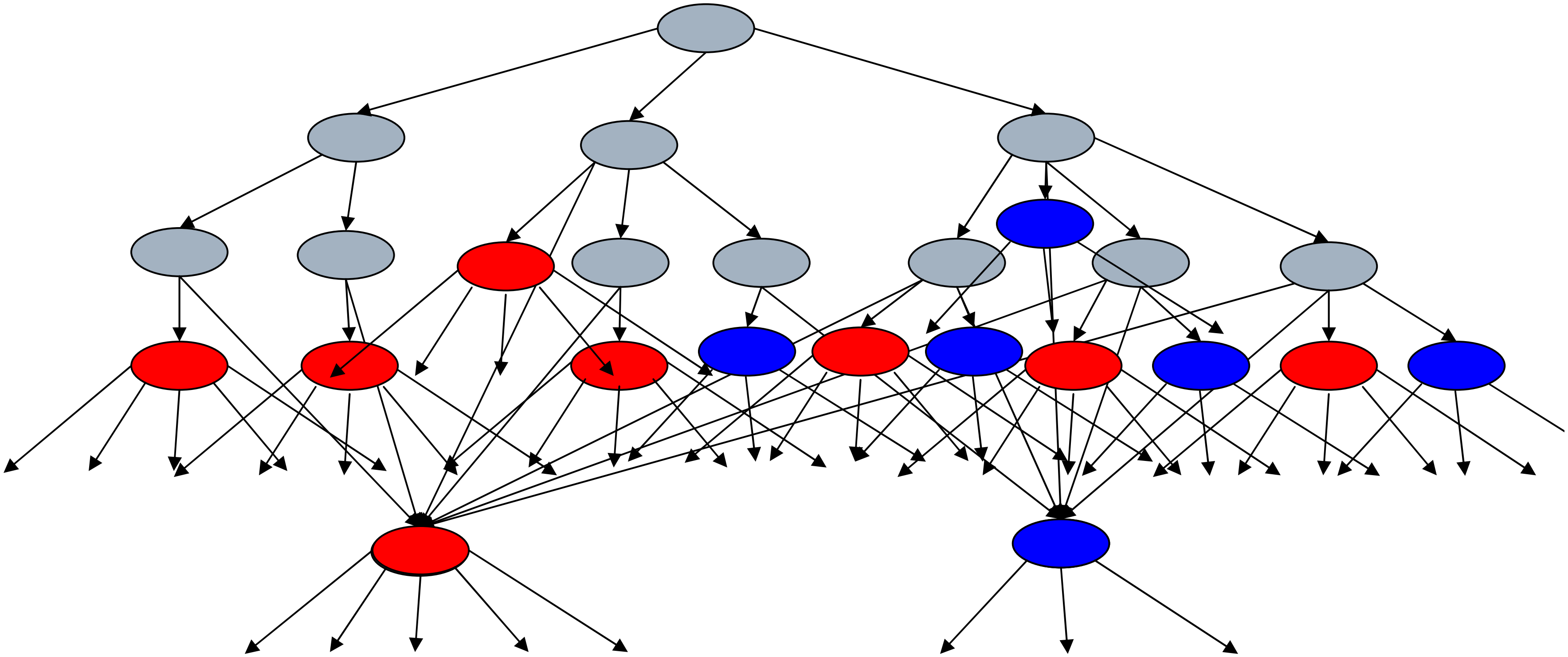
Context-sensitivity

- Context-sensitive
  - Analyze procedure for each call
- Context-insensitive
  - Analyze each procedure once
  - Merge info from all procedure calls

A simple callgraph



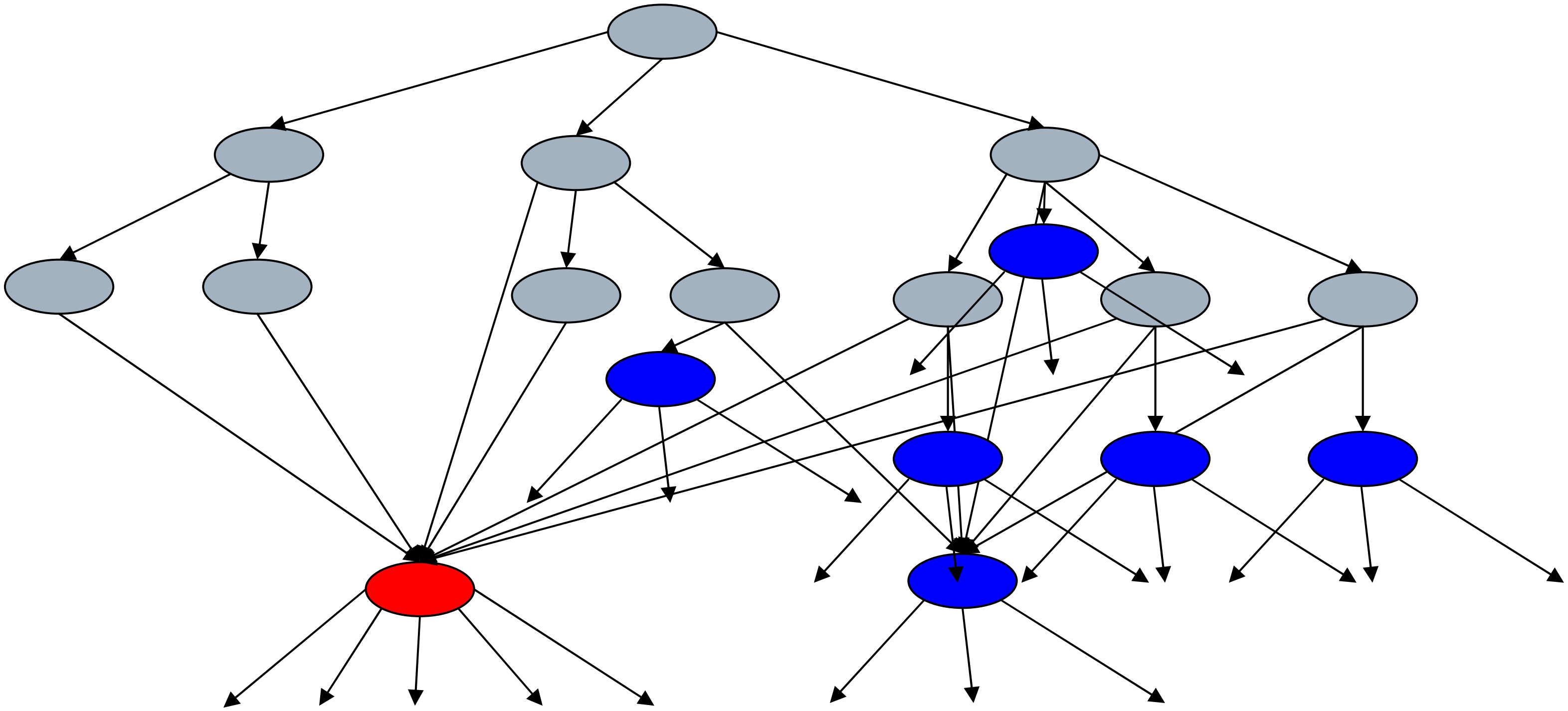
Context-sensitive



Key idea

- □ Identify when context-sensitivity is needed
- □ Use adaptive analysis [Guyer & Lin 2003]
  - ■ Quick, imprecise analysis
  - ■ Track where precision is necessary

With adaptive analysis



Evaluation

- Measured size of invocation graph
  - Indication of resulting model size
- C code programs
  - ~10Ks lines of code
  - 41 to 959 procedures and library routines
- Results from one security analysis
  - FTP behavior analysis

Motivating results

	Context-Insensitive	Context-Sensitive	Adaptive	Reduction
pfingerd	43			
muh	41			
blackhole	959			
named	311			

Insight

- Two-orders reduction in invocation graph size
  - Upper-bound because DFA adds unrealizable paths

Status & Future Work

- ☑ Translating abstracted program to model checker
- □ Understand relationship with other control abstractions
  - Partial-order reductions
  - Slicing
- □ Comprehensive integration between DFA and model checking

Questions

Model checking in one slide

- Completely determines satisfiability
- Performs an exhaustive search
- Can generate huge state-space from simple model

- Research focused on reducing state-space by over-abstracting the model

Data-flow analysis in one slide

- Determines safe, but incomplete, solution
- Iteratively solves flow equations
- Quickly converges in practice

- Adaptive analysis can identify where effort should be exerted

Best of both worlds

- Model checking and DFA are two sides of the same coin
- Completeness of model checking
- Scalability of data-flow analysis

Statement location results

	context-insensitive	adaptive	context-sensitive	reduction
pfinger	150	150	24361	162x
muh205	157	157	30114	191x
bind	1273	2061	>1449996	>703x
blackhole	3865	5265	>819997	>155x

Current status

- Implementing analysis for C programs
  - Using Broadway/C-Breeze compiler
  - Initial phase limited to typestate problems
- Output model to SPIN model checker
- Handles recursion

Conclusion

- Reduce by two orders of magnitude
  - Without other reduction techniques
- No loss of accuracy in the model check result