Generating Tests for Detecting Faults in Feature Models

Paolo Arcaini[1], **Angelo Gargantini**[2], **Paolo Vavassori**[2]

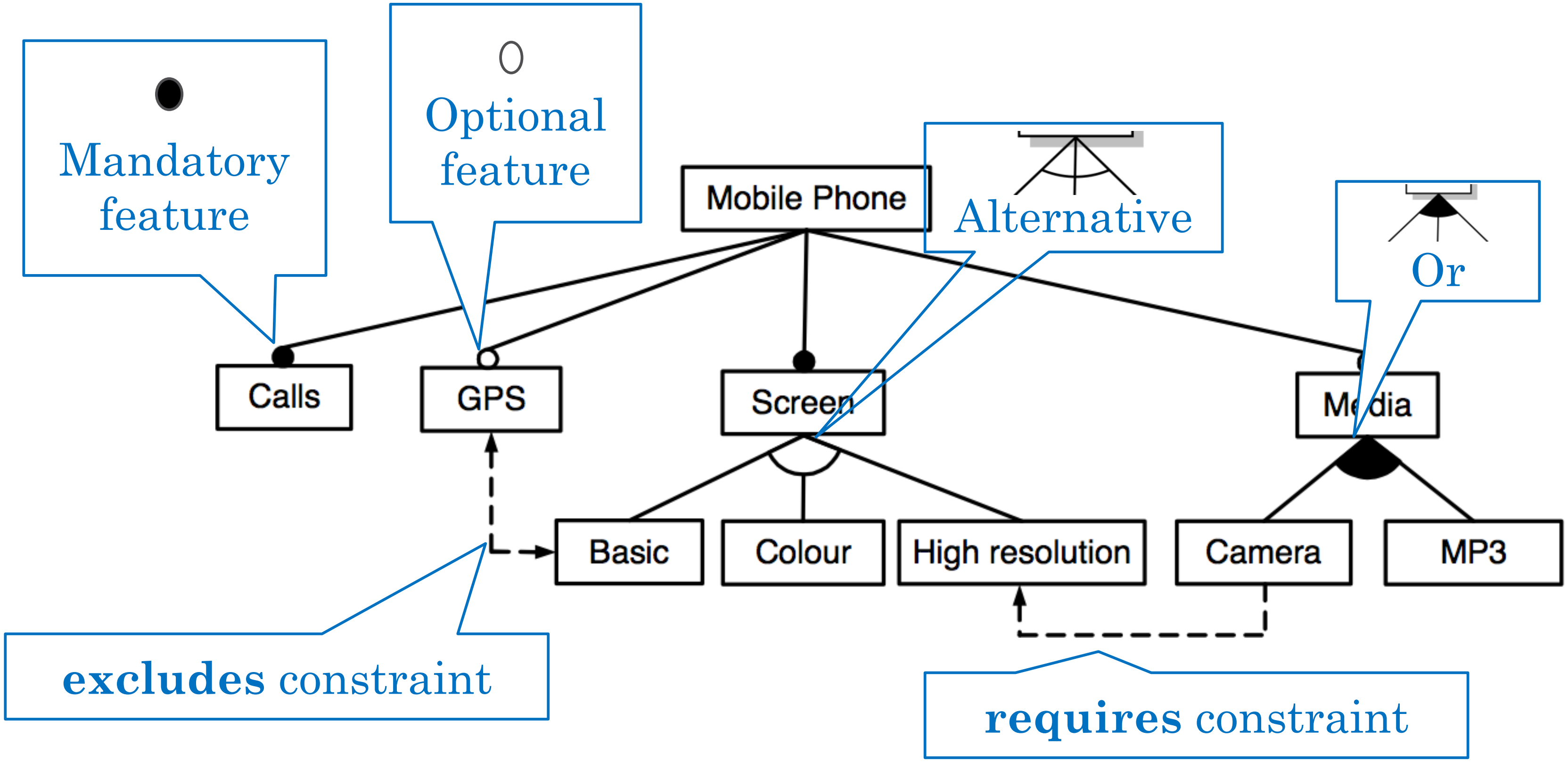
1 Charles University in Prague, Czech Republic
2 University of Bergamo, Italy

Outline

- Feature models (FM)
- Fault-based testing approach for FMs
  - Common faults and mutation operators for FMs
  - Distinguishing configuration (dc)
- Generation of *dcs*
  - Test suite that guarantees the detection of faults
- Experiments
  - Usage of *dcs*
- Conclusions

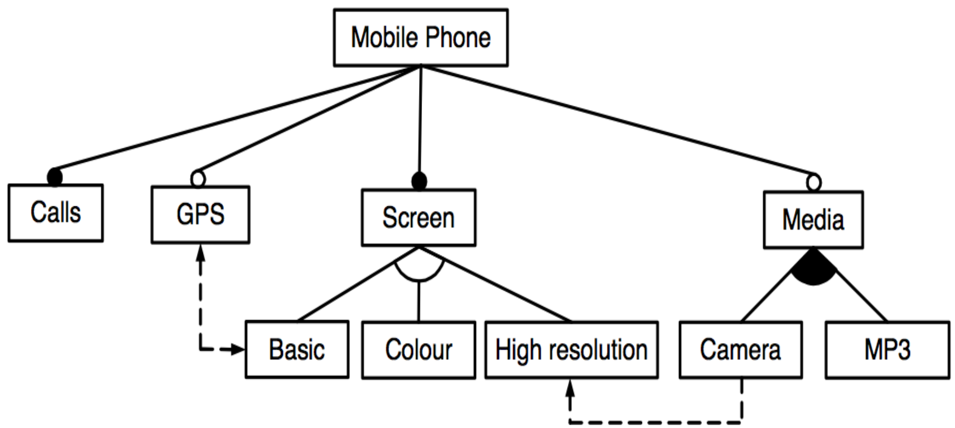
Feature models

- a **feature model** is a compact representation of all the products of the Software Product Line (SPL) in terms of "features“ and relations among them.



Configurations and products

- A configuration of a feature model M is a subset of the features in M that must include the root
- A valid configuration is called a product, since it represents a possible valid instance of the feature model



Product:

{Mobile Phone, Calls, Screen, Basic, Media, MP3}

Invalid configuration:

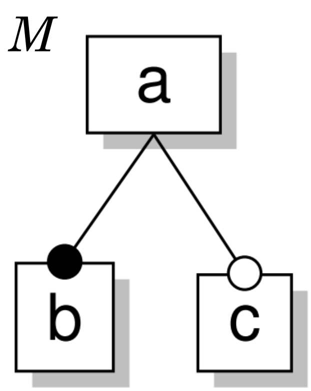
{GPS, Screen, Media}

Configurations used as tests: exhaustive coverage is unpractical. Which configurations to select?

FMs as Boolean formula

- Feature models semantics can be rather simply expressed by using propositional logic

Let **BOF** be a function that, given a feature model *M*, returns its representation as propositional formulae



BOF(M):

root mandatory optional

$$a \wedge \; a \leftrightarrow b \; \wedge c \rightarrow a$$

Fault-based testing for Feature Models

Fault-based testing approach

- Goal: demonstrate that prescribed faults are not in the artifact under test
- Assumption: the model can only be incorrect in a limited fashion specified by a relatively small set of common mistakes

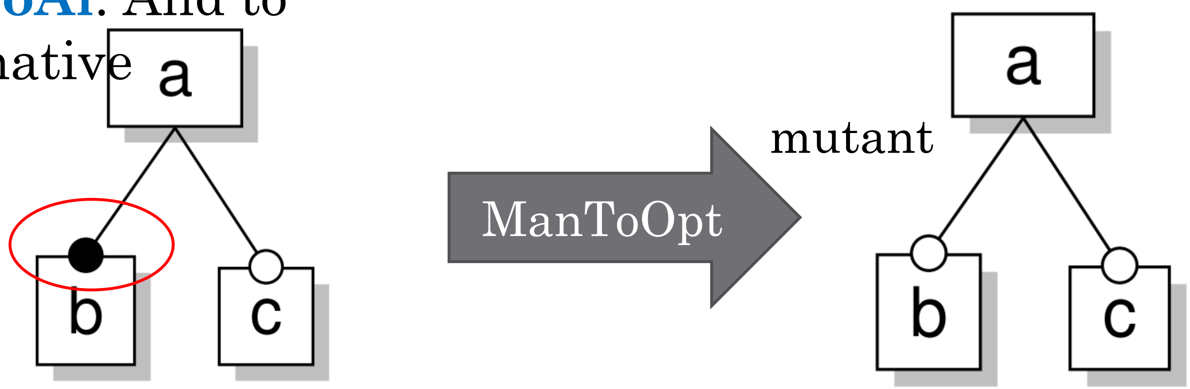
1. Fault model
   - Fault classes and mutation operators
2. A definition of the conditions able to expose the faults
3. A way to generate test that satisfy those conditions

1. Fault model - Mutation operators

- We focus on faults that can be detected by a configuration
  - may change the set of products (valid configurations)

AlToOr: Alternative to Or
AlToAnd: Alternative to And
OrToAl: Or to Alternative
OrToAnd: Or to And
AndToOr: And to Or
AndToAl: And to Alternative

ManToOpt: mandatory to optional
OptToMan: optional to mandatory
MF: a feature f is removed
MC: a constraint is removed
ReqToExcl: requires to excludes
ExclToReq: excludes to requires

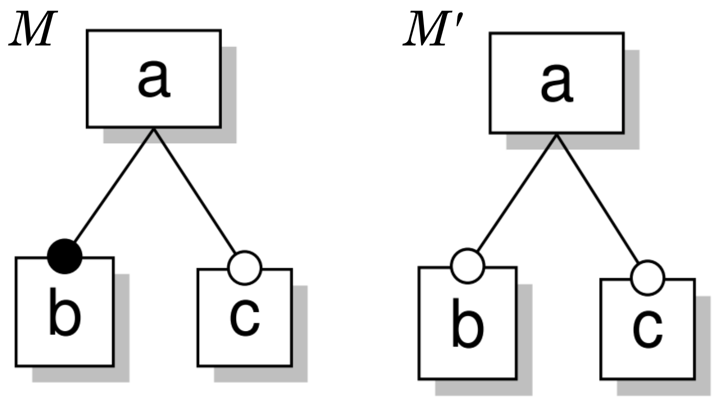


2. Distinguishing configuration

- Given a feature model M and one of its mutants M'

A configuration c distinguishes M from M'
IFF c is valid in M and not in M' or vice versa

Example

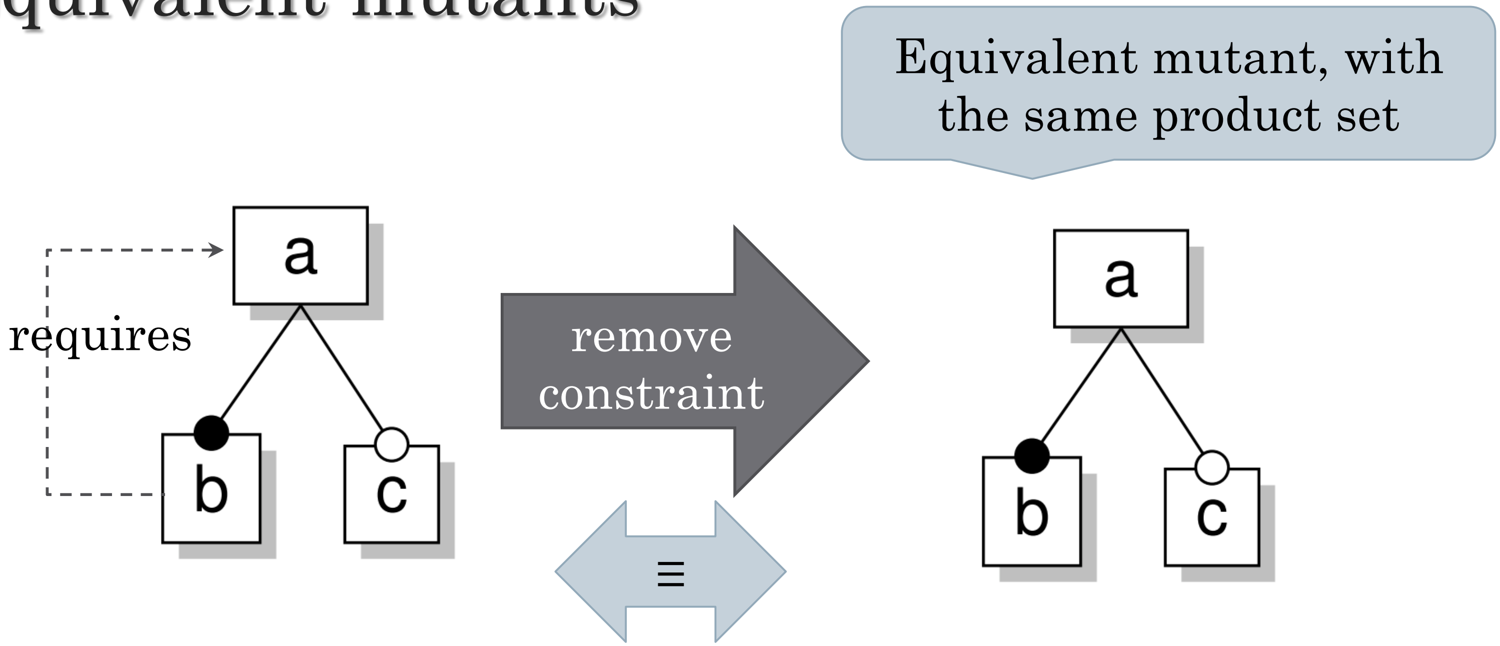


Configuration { a, b } is valid in both
It is not distinguishing

Configuration { a, c } is valid in M' but not in M
It is distinguishing

Some notes

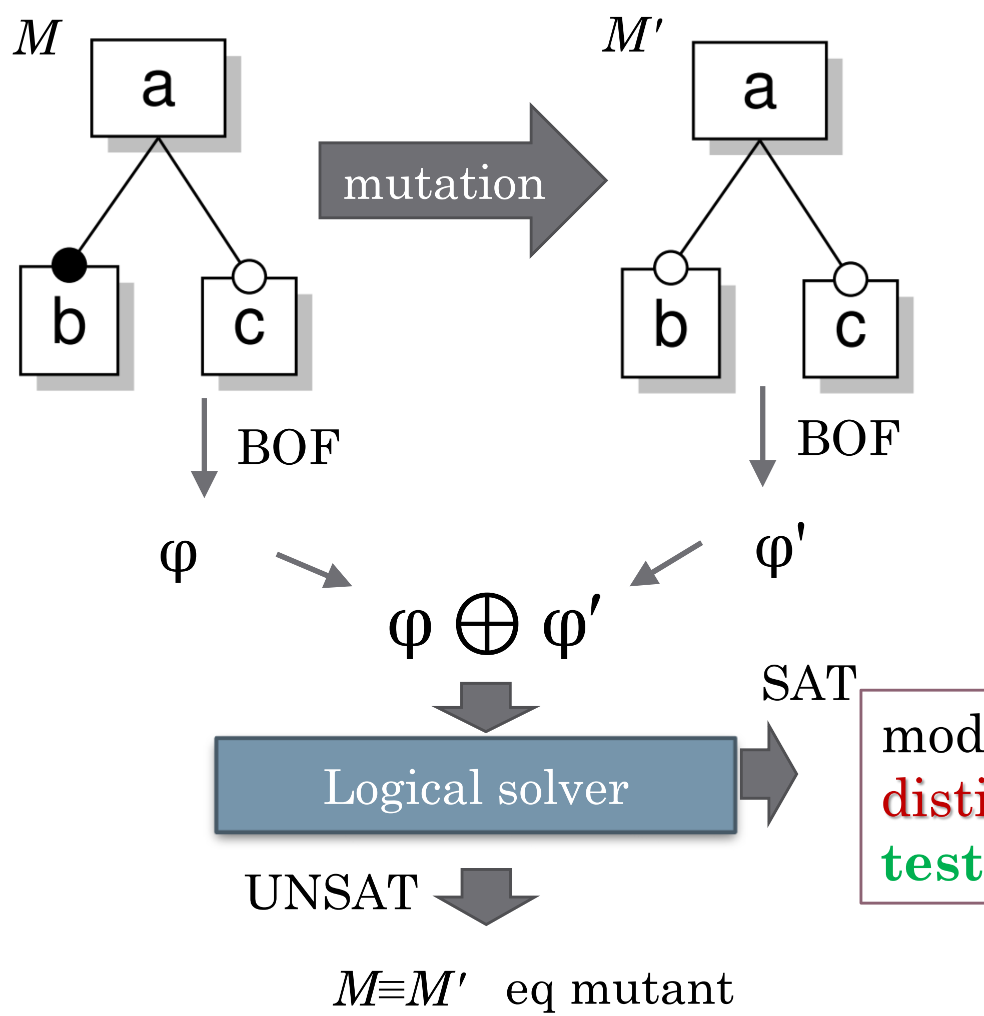
- a distinguishing configuration
  - does not need to be a valid product
  - may not exist:
    - **Equivalent mutants**



3. Generation of distinguishing configurations

- Boolean difference or derivative:
  - the erroneous implementation φ' of a Boolean expression φ can be discovered only when the expression φ ⊕ φ' is evaluated to true
  - where ⊕ denotes the logical exclusive or (xor) operator
- The generation of a distinguishing configuration can be performed by:
  1. translating M and its mutant M' by BOF
  2. using a SAT/SMT solver to get a model of the Boolean derivative

Generation of dc

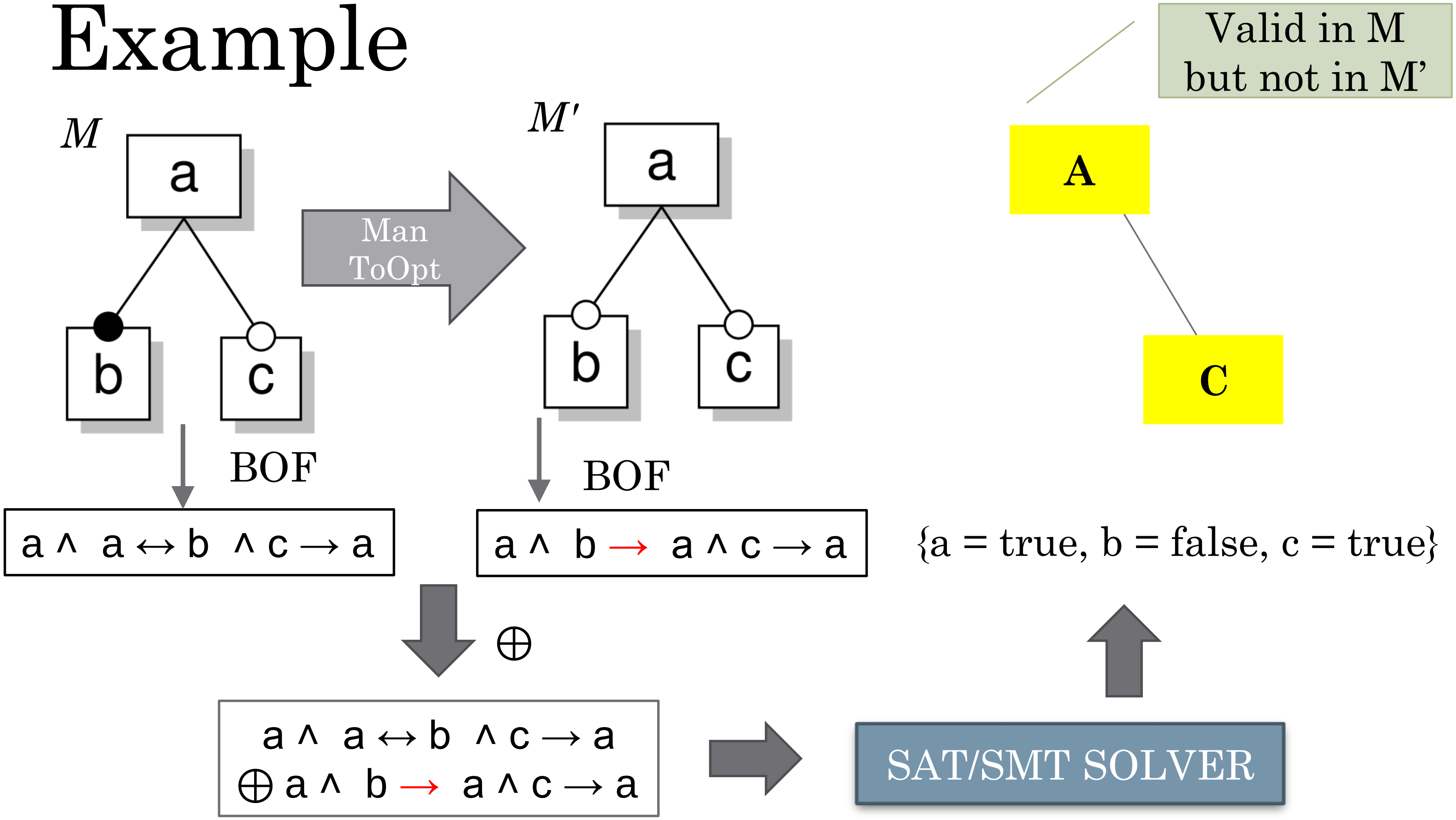


Given a FM M

1. Apply the mutation operator
2. By BOF, get the Boolean formulas for M and M'
3. Build the Boolean difference
4. Call a SAT solver

model = distinguishing configuration = test

Example


Valid in M
but not in M'
M
a
b
c
Man
ToOpt
M'
a
b
c
A
C
BOF
a ∧ a ↔ b ∧ c → a
BOF
a ∧ b → a ∧ c → a
{a = true, b = false, c = true}
⊕
a ∧ a ↔ b ∧ c → a
⊕ a ∧ b → a ∧ c → a
SAT/SMT SOLVER

Generation of a test suite

- To get a set of configurations able to detect all the faults for a given feature model:

1. generate all the mutants for the original feature model by applying one mutation at a time
2. generate a test predicate for every mutant
3. use the solver to get the model for every test predicate (or to prove that the mutant is equivalent)

- This basic process can be optimized (for producing more compact test suites and possibly save time)

Optimizations

- Process
  - **monitoring**: it checks whether a test produced for a test predicate is also a model for other test predicates
  - **collecting**: it looks for a model of a conjunction of test predicates, instead of a model for each test predicate
    - Very expensive in terms of SAT calls
  - **prioritizing**: it considers the test predicates in a particular order
  - **post reduction**: after the test generation, it removes unnecessary tests, i.e., tests that only cover test predicates that are also covered by other tests
- Logical
  - xor simplification: $(\alpha \wedge \beta) \oplus (\alpha \wedge \gamma) \equiv \alpha \wedge (\beta \oplus \gamma)$

Experiments

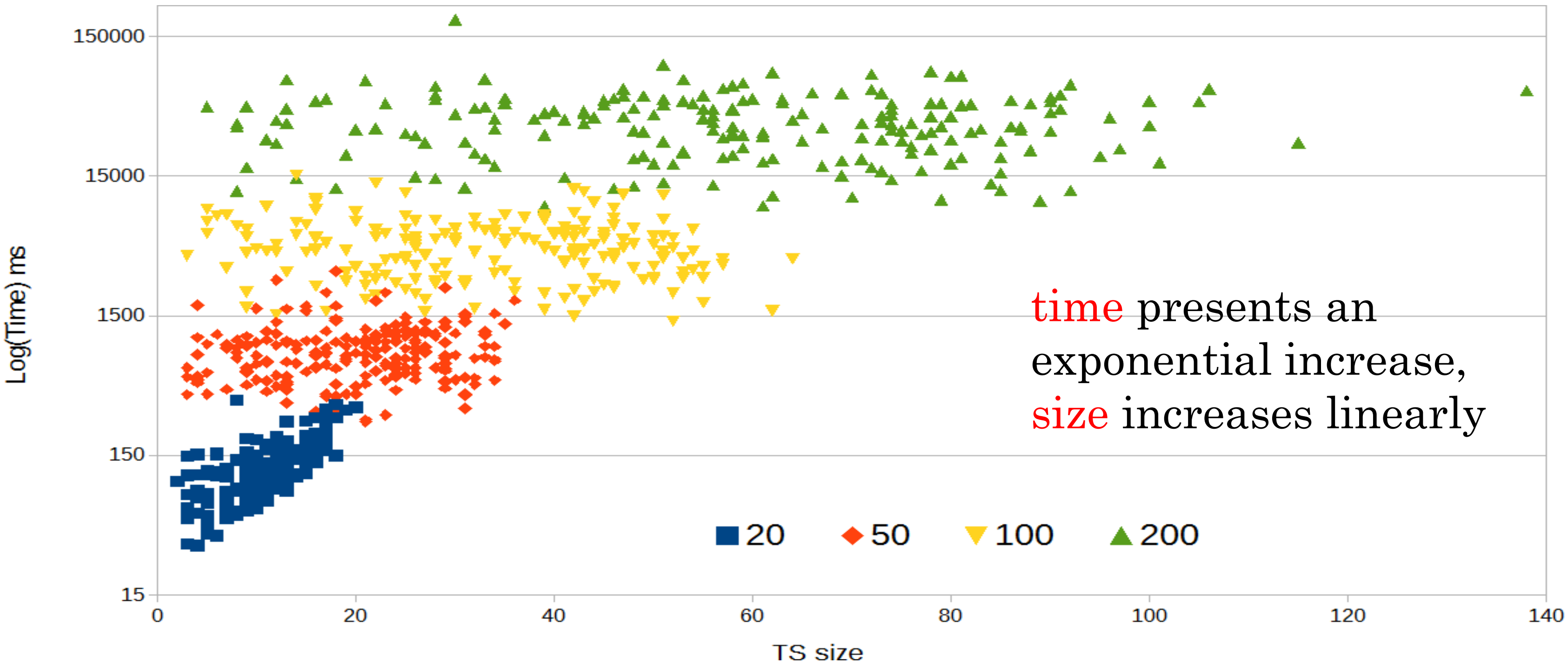
Settings

- FeatureIDE
- SMT solver Yices
- 53 models from SPLOT repository
  - From 9 to 287 features (2.48 X 10^{86} configurations)
  - From 2 to 8.53 X 10^{47} products
- 1600 artificially generated models distributed with FeatureIDE
  - having 10, 20, 50, 100, 200, 500, 1000, and 2000 features

Some preliminary research questions

- RQ1 How many mutants are generated?
  - Not so many – linear increase with the number of feature
- RQ2 How many mutants are generated by each mutation operator?
  - Half of the mutants are for missing features
- RQ3 How are mutants distributed in the Feature Models edit classes {*Refactoring, Specialization, Generalization, Arbitrary edit*}?
  - Details in the paper
- RQ4 Is the simplification of the xor expressions effective?
  - A lot

RQ5 How big are the fault-detecting test suites? How much time is required to generate them?



- Artificial models - for models up to 200 features:
  - Average time 38 seconds
  - Average size is 60 tests (instead of 2^{200} configurations)

RQ5 How big are the fault-detecting test suites? How much time is required to generate them?

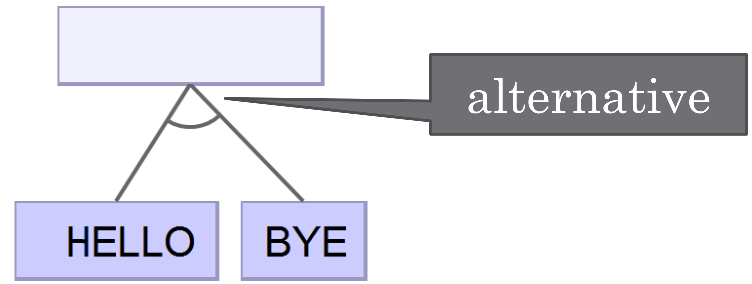
- SPLOT models
  - From 9 to 287 features (2.48×10^{86} configurations)

	TS Size	Time (ms)	#Infeasibl e
Min	4	27	0
Mean	19.9	5,264	0.49
Max	134	137,029	8

Much fewer infeasible tests than artificial models: fewer eq mutants means better quality?

Example of use for distinguishing configuration

```
#ifdef HELLO
char* msg = "Hello!\n";
#endif
#ifdef BYE
char* msg = "Bye bye!\n";
#endifn
main() {
        printf(msg);
}
```



Configurations:
{HELLO} is valid
{HELLO,BYE} is invalid

Confirmed by the compiler
(msg is declared twice)

- How to detect faults in the feature model for C code:
  - generate the distinguishing configurations and check that the oracle (compiler) confirms its validity value

RQ6 Are distinguishing configurations useful?

- Experiment of typical use of distinguishing configurations:
- We have taken 6 small programs from the literature regarding the synthesis of feature models from preprocessor directives of C/C++ source code
- We have instructed 6 students and asked them to build the 6 feature models
- Each configuration represents an option set to be given to the compiler
- We can use the compiler as oracle to judge if a configuration is valid (product) or not
- We have generated the distinguishing configurations and checked with the compiler

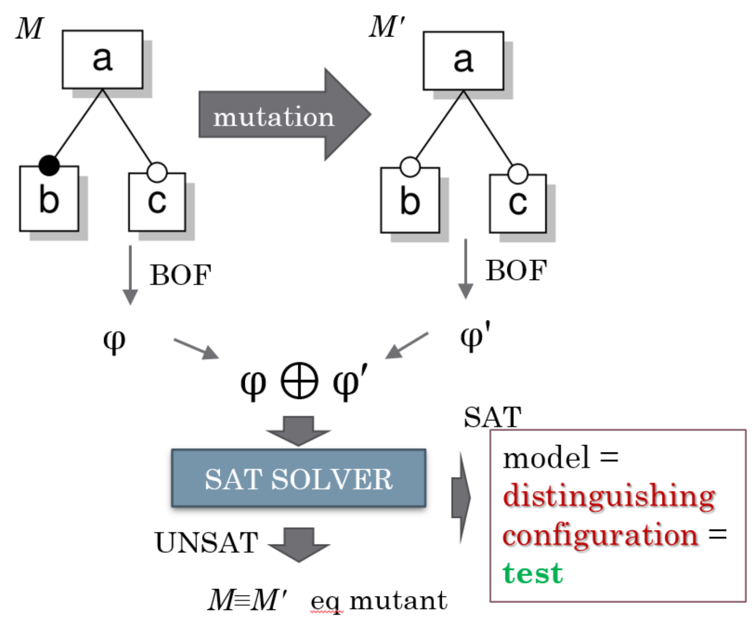
Results - comparison w.r.t. other techniques

Technique	#tests	#failing tests	#faulty models (fm)	tests/fm
Distinguishing configurations	109	12	10	10.9
Pairwise	165	12	5	33
All Products	285	23	5	57
All configurations	516	119	17	30.4

- Our approach produces the minimum number of tests and it is able to discover 59% of the faulty models
  - much more effective than other techniques
  - but <u>not all the faults</u> were detected
- The coupling effect does not hold in our case
  - The component programmer hypothesis may not be true
  - New mutation operators or HOM

Conclusions

- a configuration is distinguishing (dc) if it can characterize a feature model w.r.t. a faulty version of it
- generation of dc by:
  - translating FMs to Boolean formulas,
  - making the derivative (xor) and
  - using SAT for test generation
- the technique is effective
  - but some faults may be undetected



Thank you