Systematic Product Line Testing: Methodologies, Automation and Industrial Application

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Where do I work?

[simula . research laboratory]
- by thinking constantly about it *

- Located in Oslo, Norway
- Founded in 2001
- Non-profit, public utility enterprise, organized as a limited company owned by the Ministry of Education and Research.
- www.simula.no

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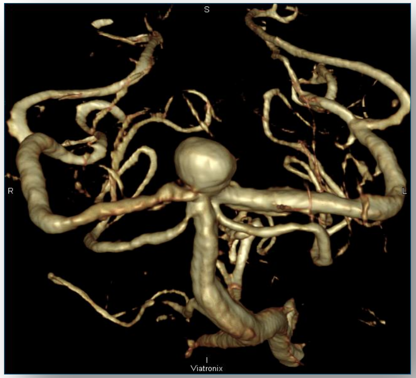
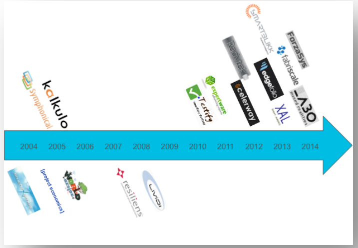
Simula conducts research, education and innovation in communication systems, scientific computing, and software engineering.



282

84



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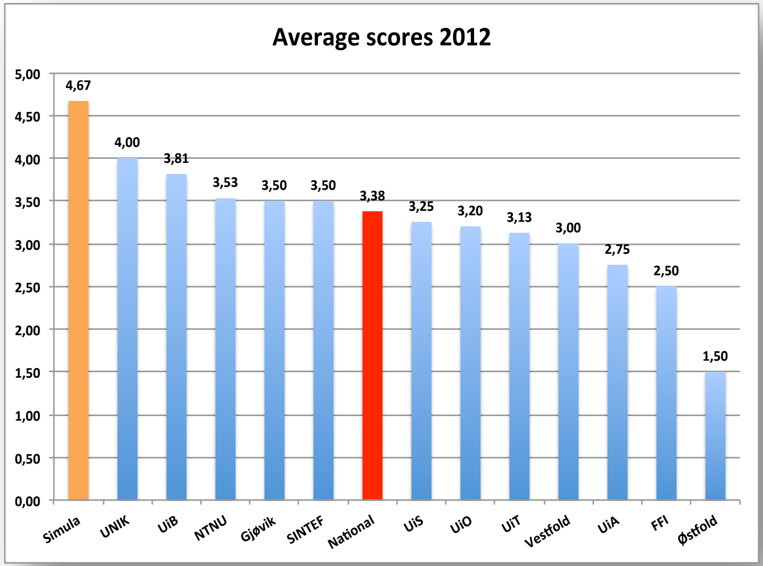
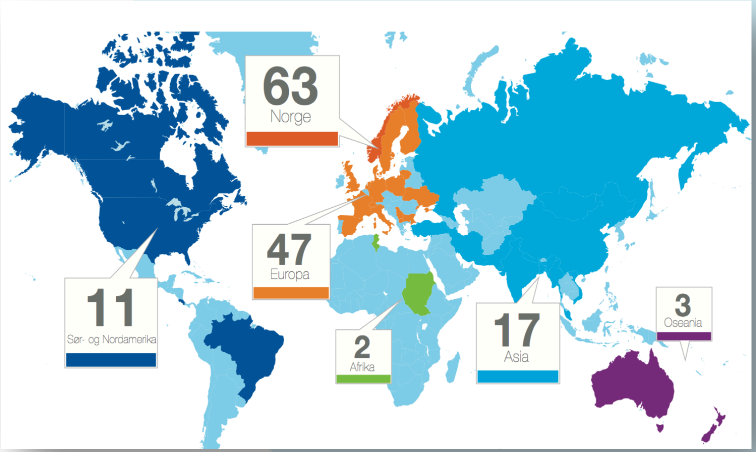
Simula has two critical assets for European collaboration: Scientific excellence and international networks





62 research groups evaluated by the National Evaluation of Research in ICT,
5 groups rated Excellent,
of which 2 at Simula (one is Software Engineering)

143 employees
> 30 nationalities

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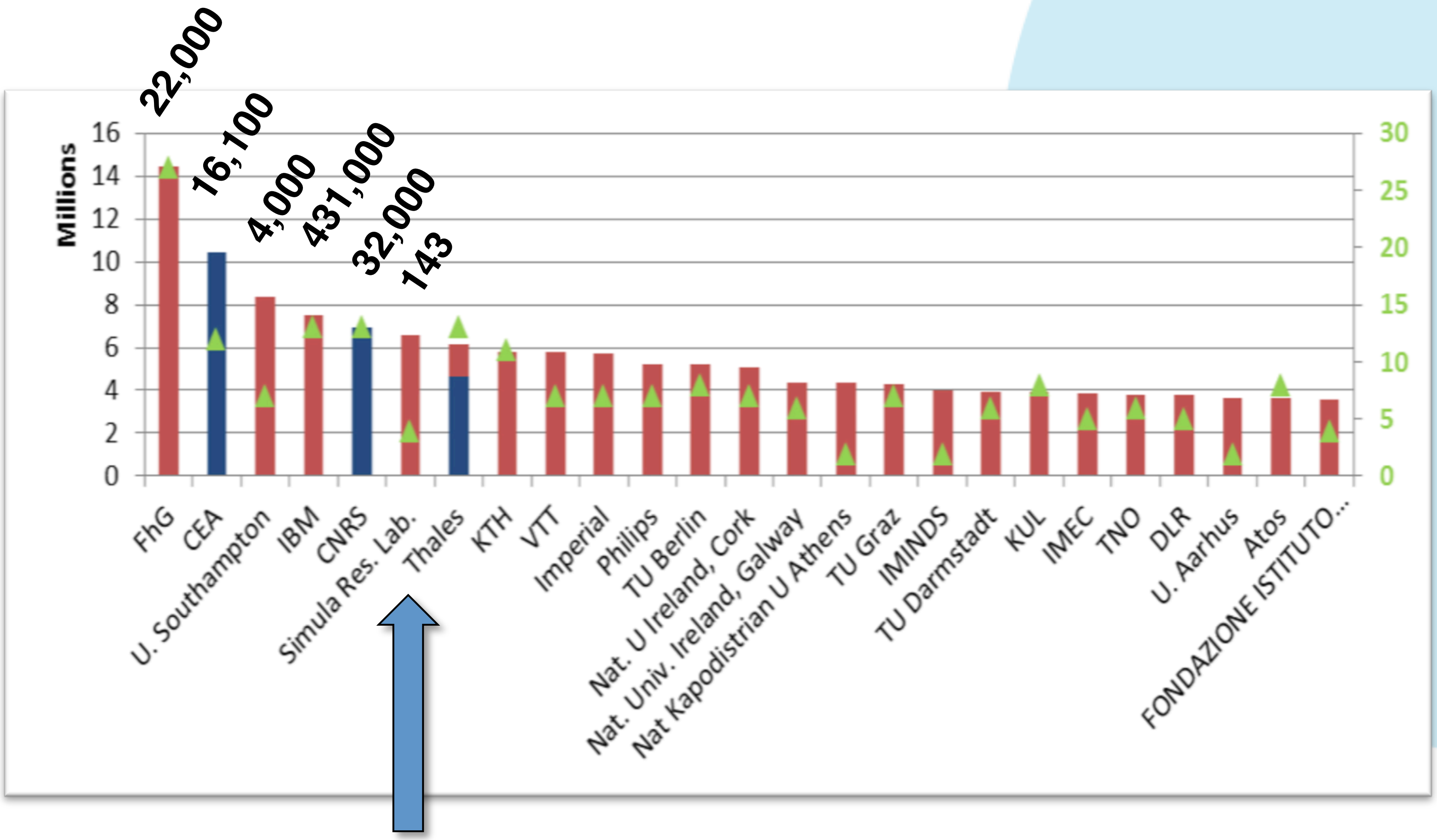
Simula is the 6th largest recipient of funding in LEIT-ICT 2014



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Software Engineering Department

- Main Research Areas
  - Model-based verification and validation of software-intensive systems (e.g., CPSs)
  - Software evolution, effort and quality estimation
- Profile
  - Ranked as the second most publishing software engineering research group in the world
  - Was evaluated as "Excellent" by the Research Council of Norway
- Close collaboration with industry

Software Engineering Department

Cisco Systems Norway

Cancer Registry of Norway

ABB Robotics
Stavanger

Kongsberg Maritime

Norwegian Custom and excise

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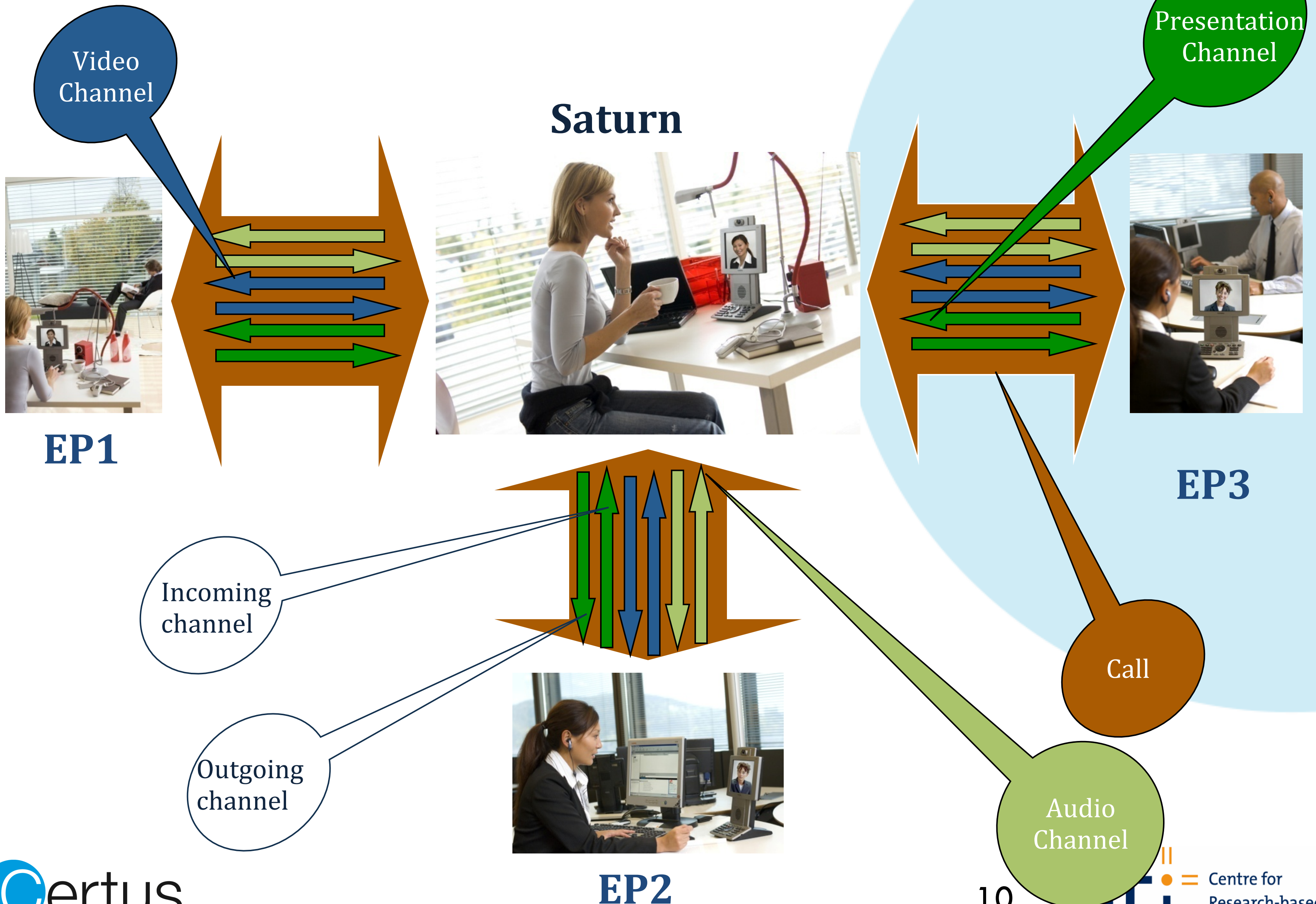
Outline

- Industrial Case Study
- Motivation
- Methodologies and Key Results

Industrial Case Study

Video Conferencing System (VCS)



Context: Video Conferencing System Product Line

C20

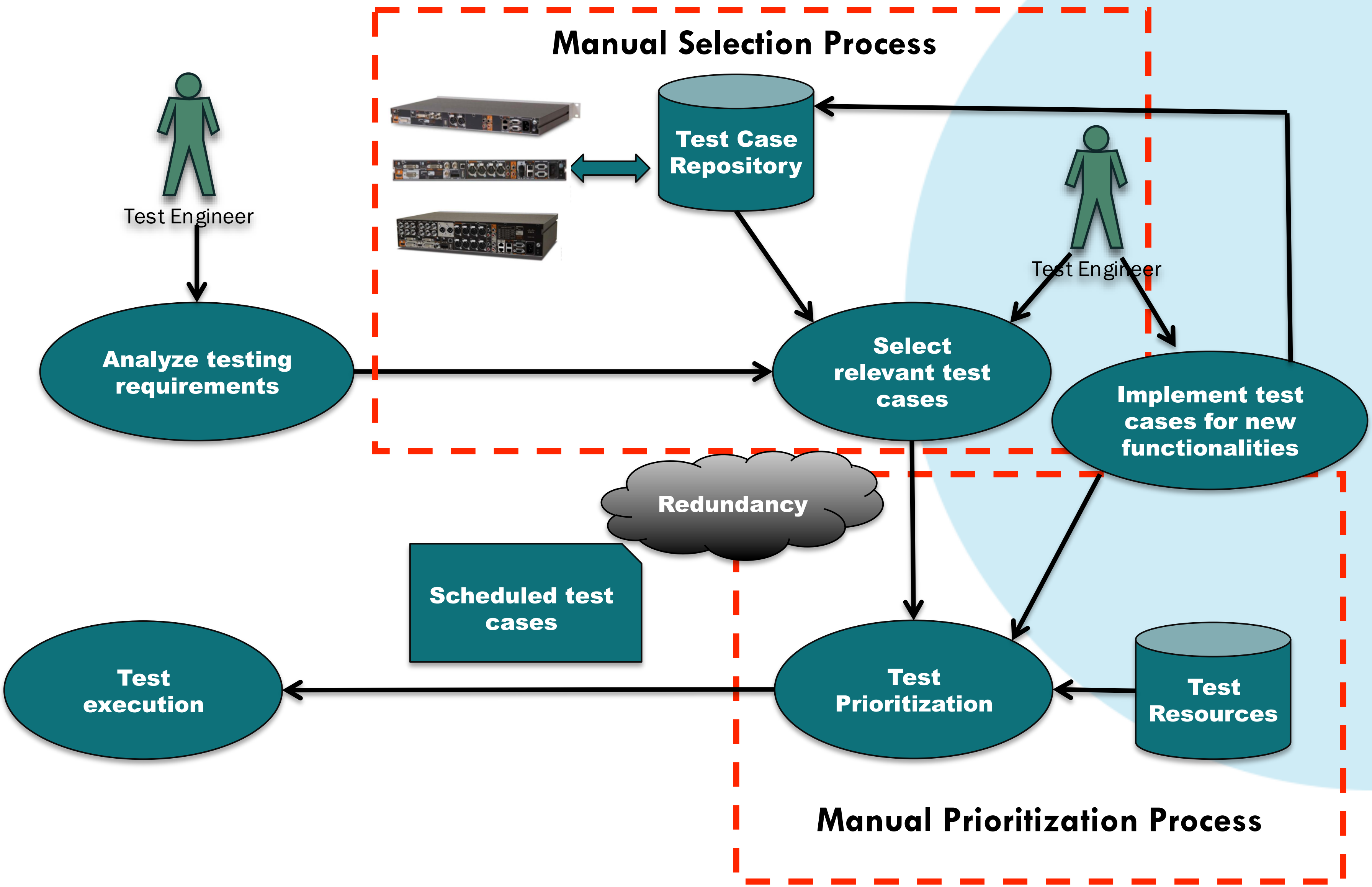
C40

SX20

C60

C90

Motivation



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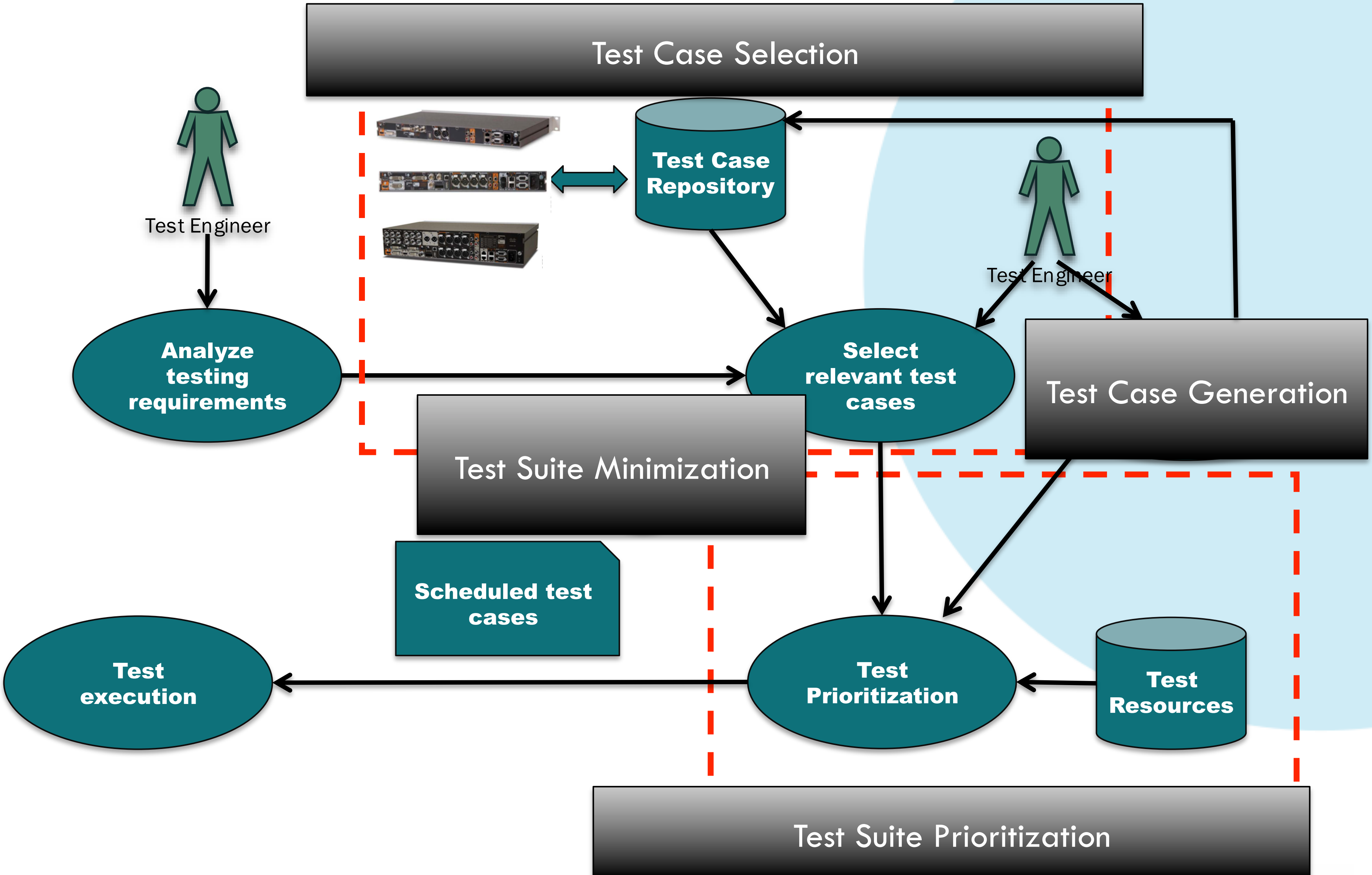
Challenges

- Time-consuming and error-prone
- Largely depend on domain expertise
- Low test efficiency
- Not repeatable and scalable

Research Problems



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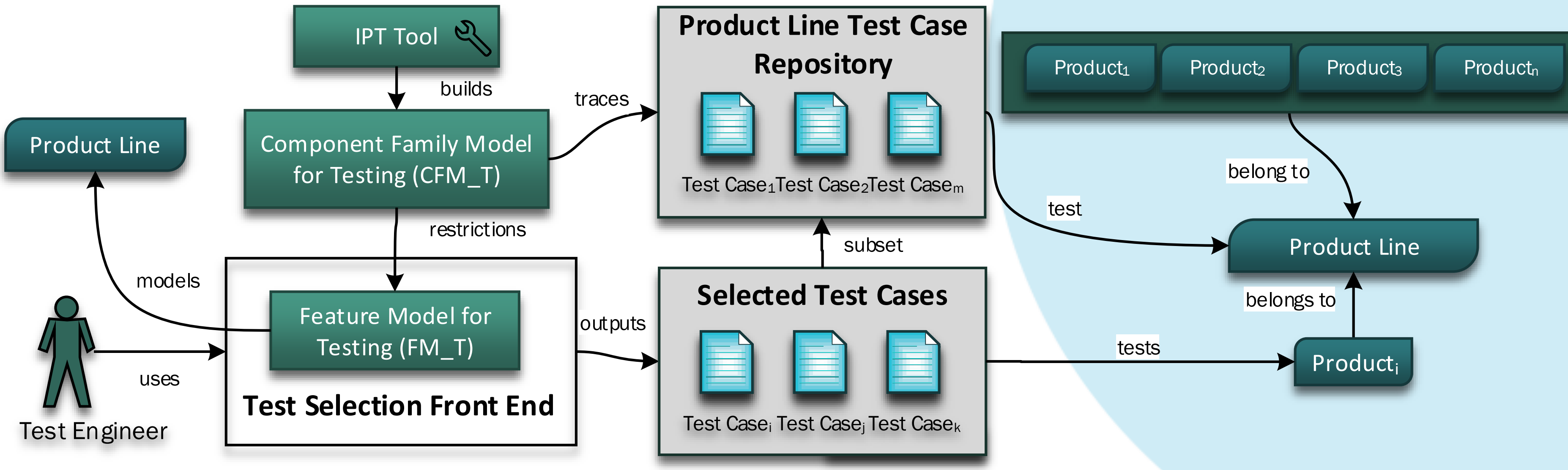
Methodologies and Key Results

Test Selection:
Test Selection Methodology using Feature Model



- Wang, S., Ali, S., Gotlieb, A., and Liaaen, M. **Automated Product Line Test Case Selection: Industrial Case Study and Controlled Experiment.** Journal of Software and Systems Modeling (SOSYM), vol 16(2), pp. 417-441, 2017.
- Wang, S., Ali, S., Gotlieb, A., and Liaaen, M. **A Systematic Test Case Selection Methodology for Product Lines: Results and Insights from an Industrial Case Study.** Journal of Empirical Software Engineering (EMSE), vol 21(4), pp. 1586-1622, 2016.
- Wang, S., Gotlieb, A., Ali, S., and Liaaen, M. **Automated Selection of Test Cases using Feature Model: An Industrial Case Study.** In: Proceedings of the 16th International Conference on Model-Driven Engineering Languages and Systems (MODELS 2013), **Best Application Paper Award**, pp. 237-253, 2013.

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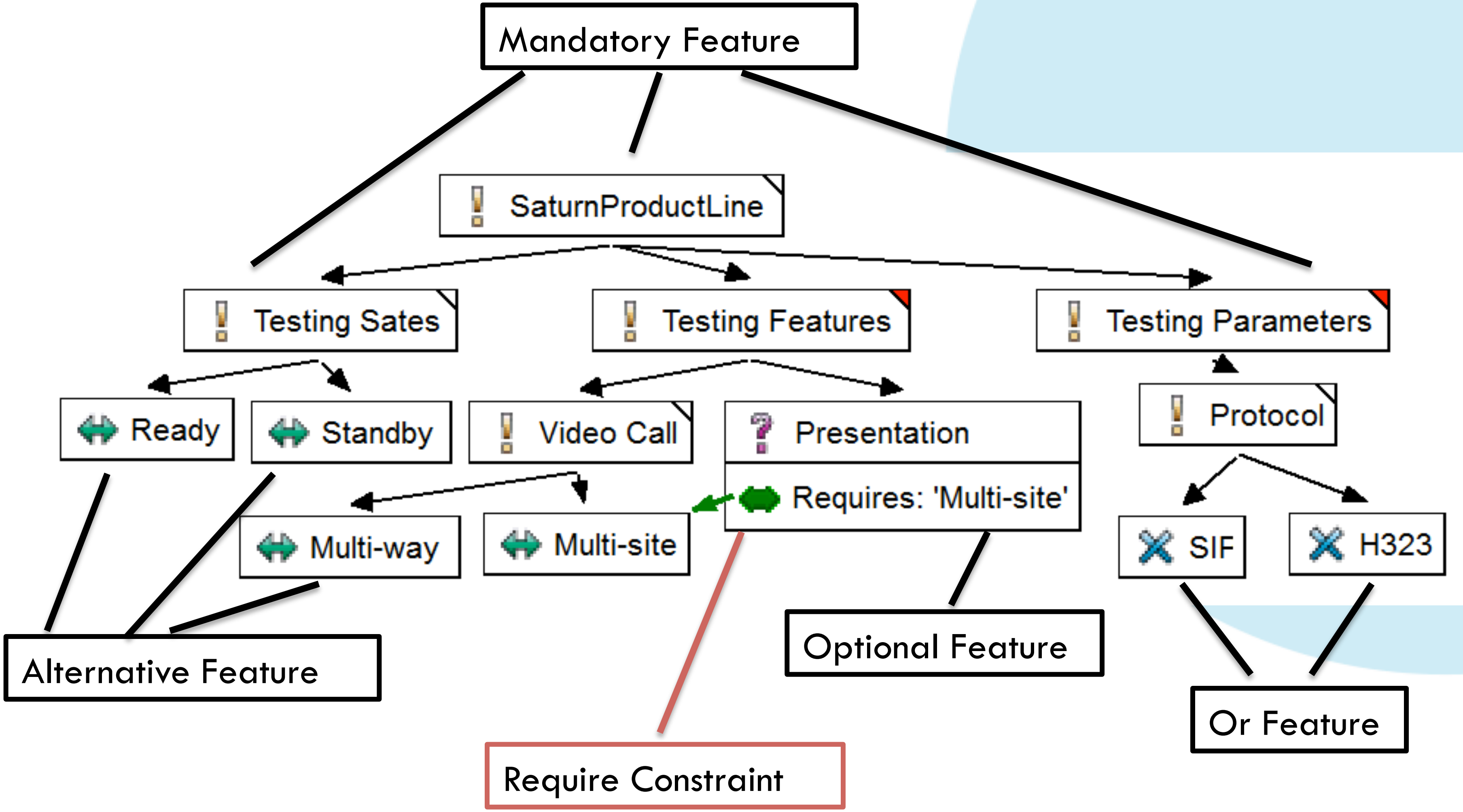
FM_T



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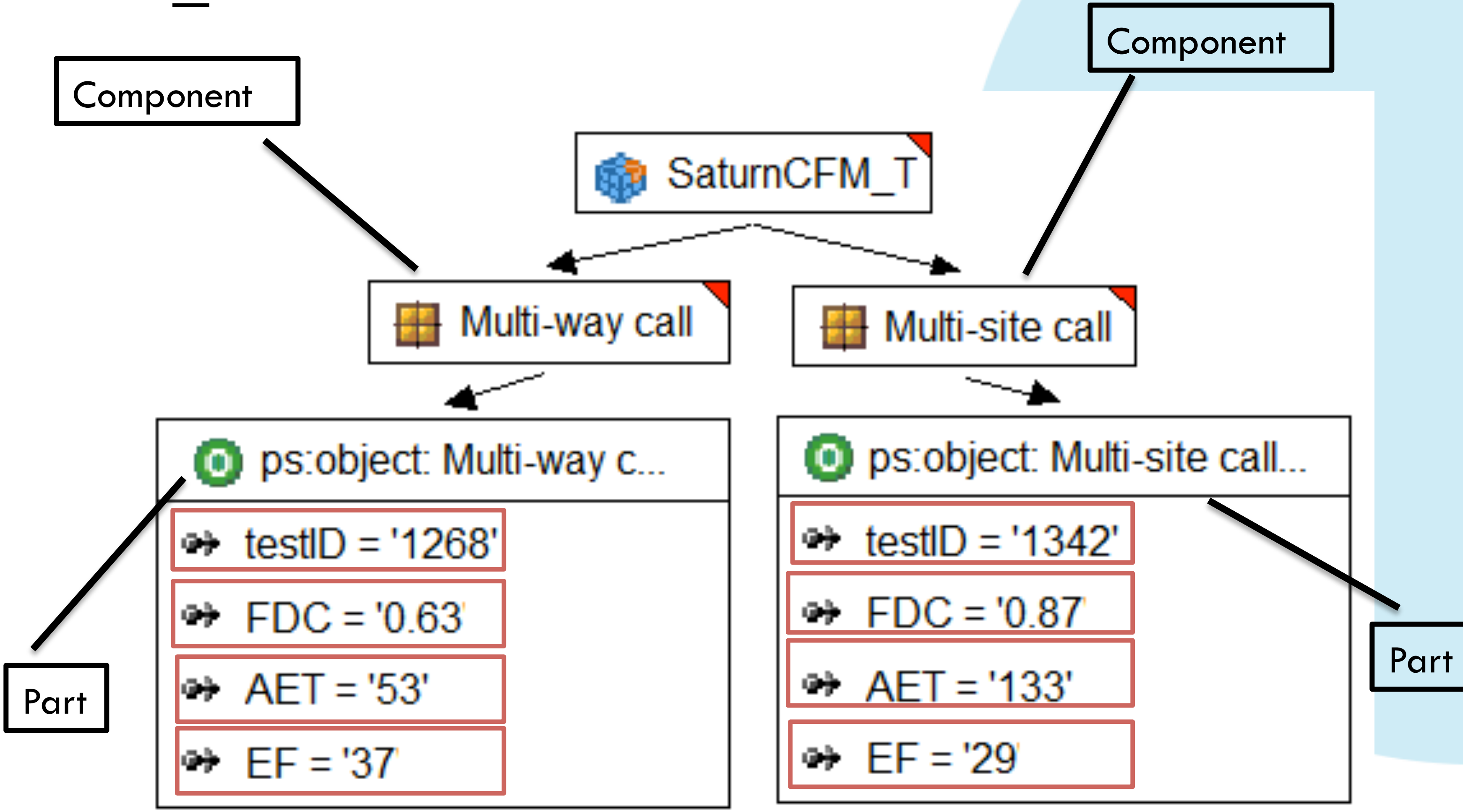
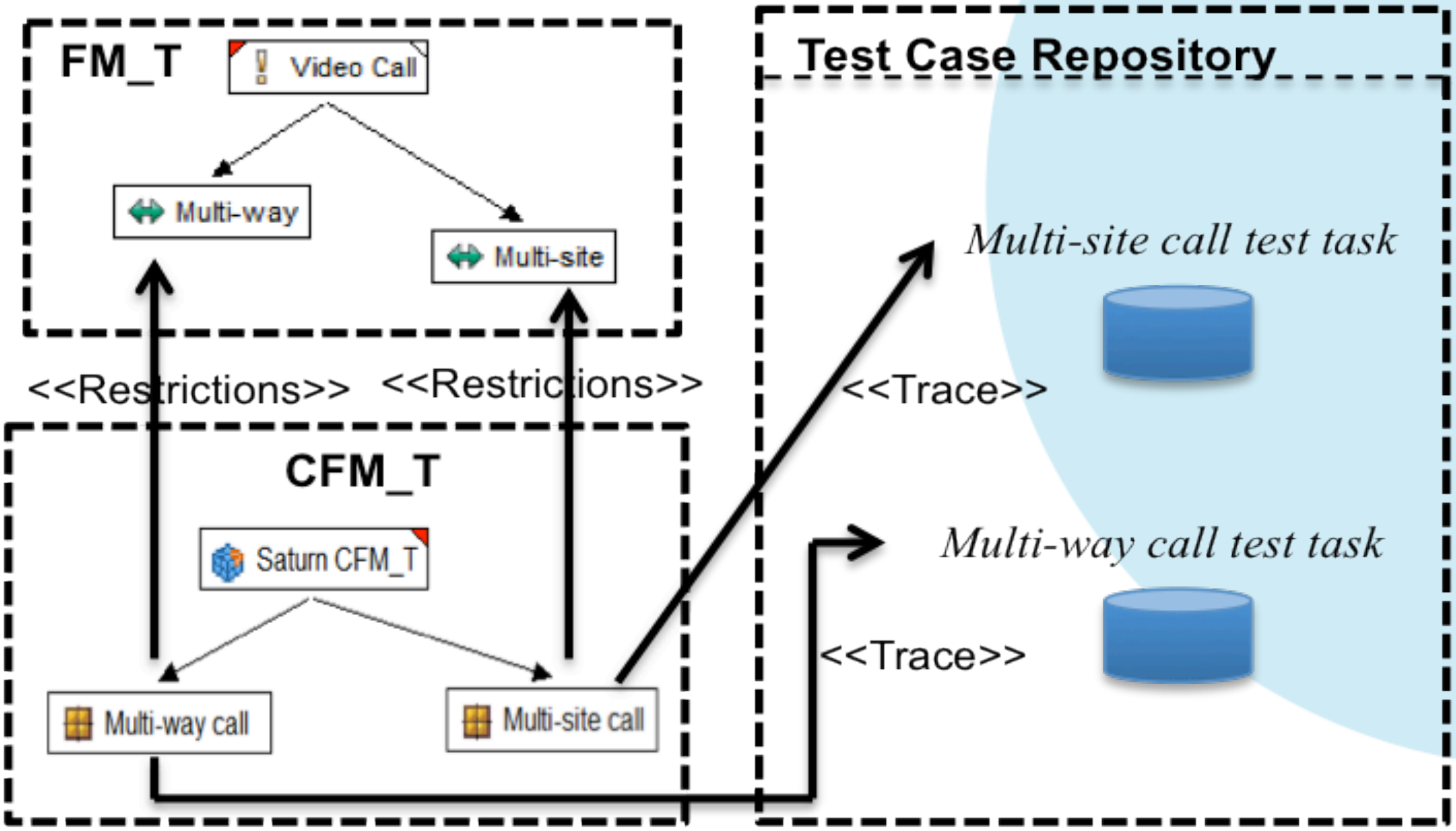
CFM_T


Component
SaturnCFM_T
Component
Multi-way call
Multi-site call
ps:object: Multi-way c...
ps:object: Multi-site call...
testID = '1268'
FDC = '0.63'
AET = '53'
EF = '37'
testID = '1342'
FDC = '0.87'
AET = '133'
EF = '29'
Part
Part

Configuration Process



Evaluation: Industrial Case Study

- Seven VCS products (C20, C40, C60, C90, SX200, MX200 and MX300)
- Reduced selection effort on average: 83%

Discussion

- Abstraction and automation
  - Hide the implementation details
  - No need to go through test cases manually
- Improved effectiveness
- Less reliance on domain knowledge

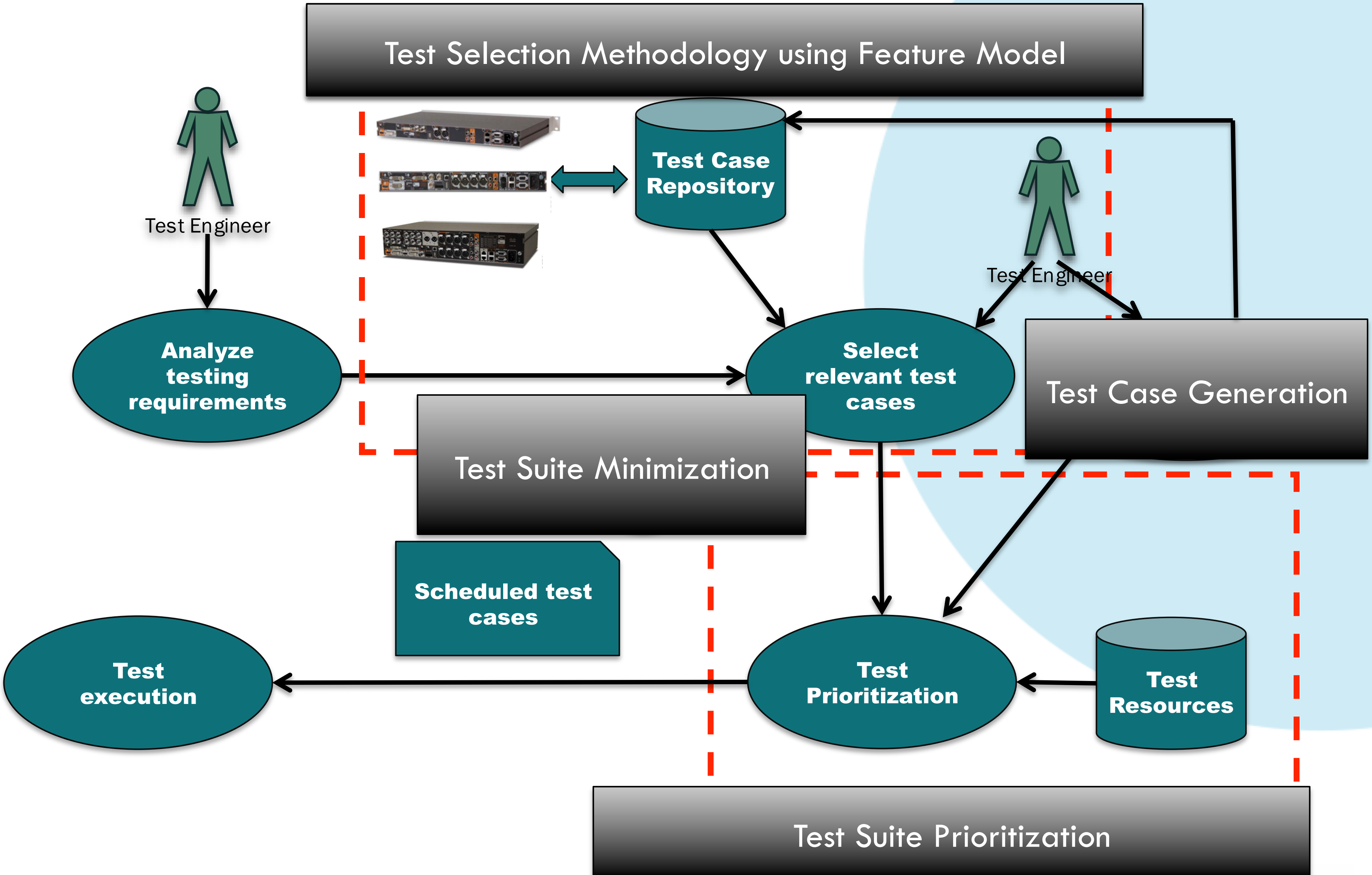
Controlled Experiment

- Goal
  - compare cost, effectiveness, and efficiency of our methodology with the manual approach

- Plan and design
  - 20 graduate students divided into two groups
  - One cost measure, four effectiveness measures and two efficiency measures

- Results show the methodology can significantly reduce the cost and improve the effectiveness and efficiency

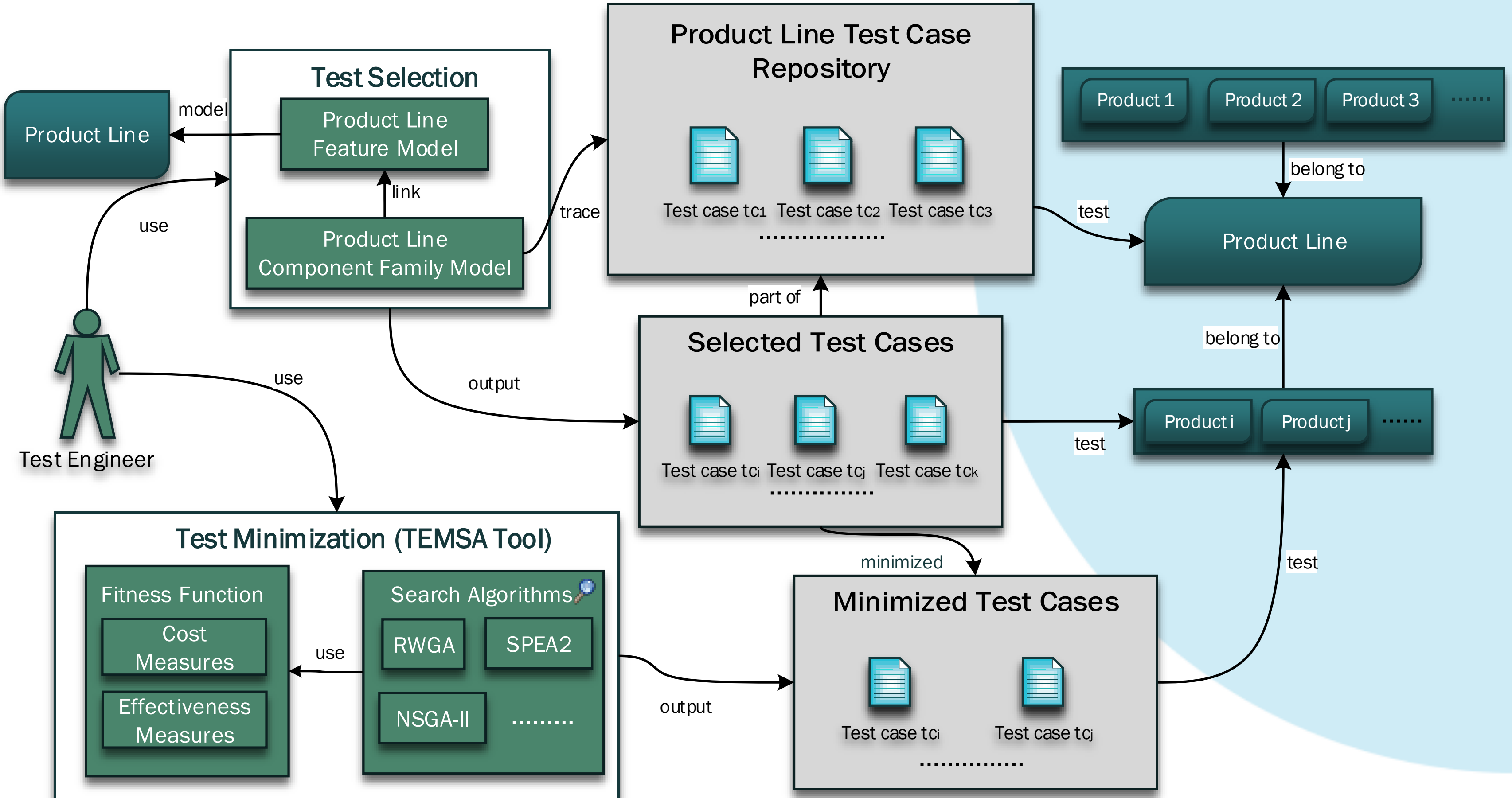
Research Problems



Test Minimization:
Search-Based Test Minimization Approach

Fitness Function

Search-Based Test Minimization Approach



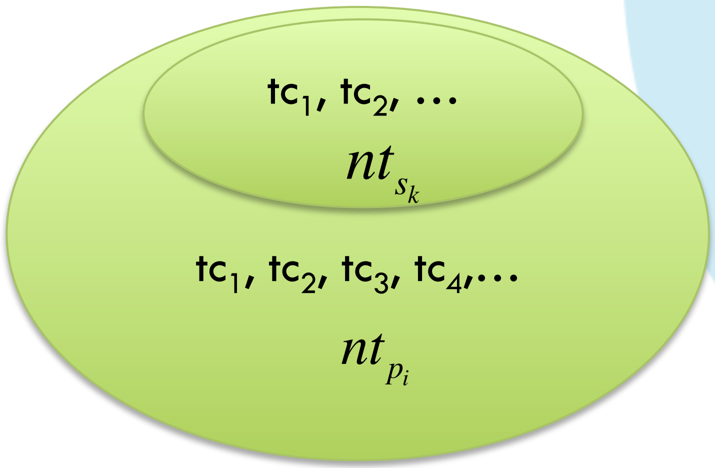
- Wang, S., Ali, S., and Gotlieb, A. **Cost-Effective Test Suite Minimization in Product Lines Using Search Techniques.** Journal of Systems and Software (JSS), vol (103), pp. 370-391, 2015.
- Wang, S., Ali, S., and Gotlieb, A. **Random-Weighted Search-Based Multi-Objective Optimization Revisited.** In: Proceedings of the 6th International Symposium on Search-Based Software Engineering (SSBSE), pp. 184-198. 2014.
- Wang, S., Ali, S., and Gotlieb, A. **Minimizing Test Suites in Software Product Lines using Weight-Based Genetic Algorithms.** In: Proceedings of the 15th International Conference on Genetic and Evolutionary Computation Conference (GECCO 2013), pp. 1493-1500, 2013.

Cost-Effectiveness Measures

- Cost
  - Overall Execution Time (*OET*)
    - Measure the amount of time used by a solution
- Effectiveness
  - Test Minimization Percentage (*TMP*)
    - Measure how many test case can be reduced
  - Feature Pairwise Coverage (*FPC*)
    - Measure how many feature pairs can be covered
  - Fault Detection Capability (*FDC*)
    - Measure how many test cases in the solution can find faults
  - Average Execution Frequency (*AEF*)
    - Measure how often test cases in the solution are executed

Test Minimization Percentage (TMP)

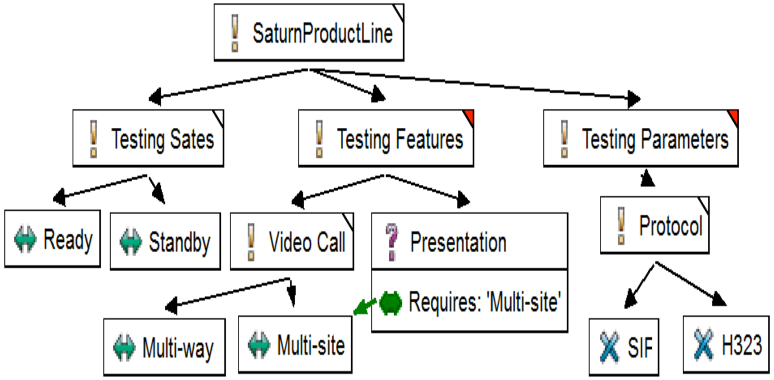
TMP is used to measure the amount of reduction in the number of test cases



$$TMP_{s_k} = (1 - \frac{nt_{s_k}}{nt_{p_i}})$$

Feature Pairwise Coverage (FPC)

FPC is used to measure how much pairwise coverage can be achieved by a chosen solution.



Pairs

- (Multi-way, SIF)
- (Multi-way, H323)
- (Multi-site, SIF)
- (Multi-site, H323)
- …

$$FPC_{s_k} = \frac{Num\_FP_{s_k}}{Num\_FP_{p_i}}$$

Search Algorithms

Different Mechanisms			Algorithms	Minimization Before?
Evolutionary Algorithms (EAs)	GAs	Weight-Based GA	WBGA	Yes
			WBGA-MO	Yes
			RWGA	Yes
		Sorting-Based GA	NSGA-II	Yes
		Cellular-Based GA	MOCell	No
	Strength Pareto EA		SPEA2	Yes
	Evolution Strategies		PAES	No
Swarm Algorithm	Particle Swarm Optimization		SMPSO	No
Hybrid Algorithm	Cellular genetic algorithm + differential evolution		CellDE	No
Stochastic Algorithm	Random Search		RS	Yes

$$Fitness = f(TMP, FPC, FDC, OET, AEF)$$

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Industrial Case Study and Artificial Problems

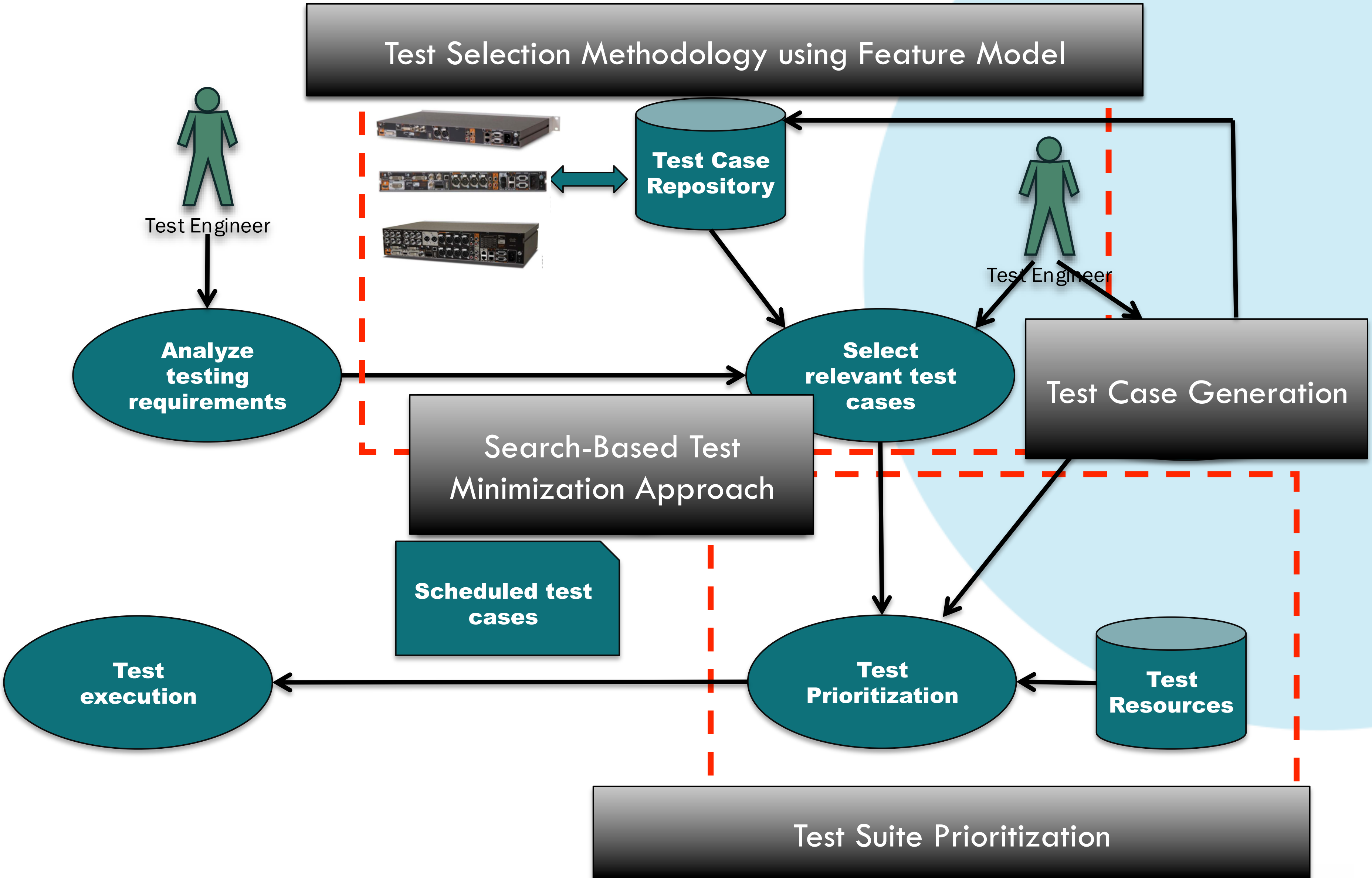
- Industrial Case Study
  - C20
  - C40
  - C60
  - C90

- 500 Artificial Problems
  - 1200 features
  - 60000 test cases

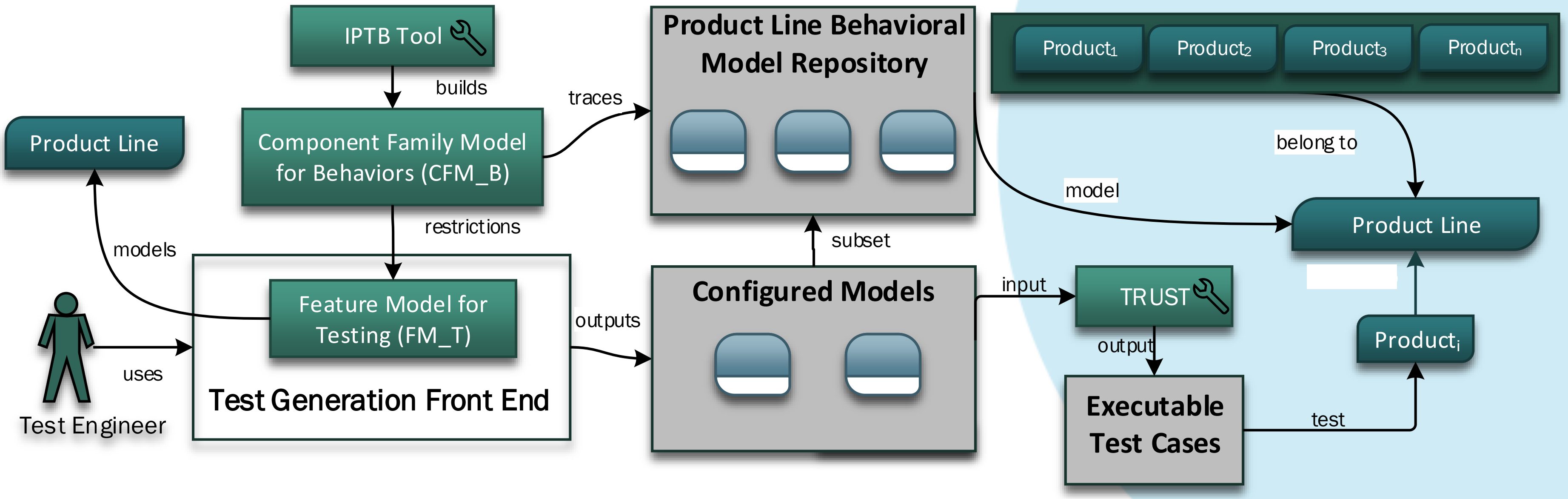
Key Results for Evaluation

- Industrial Case Study
  - Search algorithms can achieve the acceptable level for test minimization in terms of cost and effectiveness
  - Random-Weighted Genetic Algorithm (RWGA) achieves the best performance when considering all the objectives together
- 500 Designed Artificial Problems (Varying Complexity)
  - Similarly as industrial case study
  - Search algorithms can preserve high performance as the increasing complexity of problems

Research Problems



Test Generation:
Using Feature Model to Support Model-based Testing



- ❑ Select features in FM_T through the *Selection Front-end*

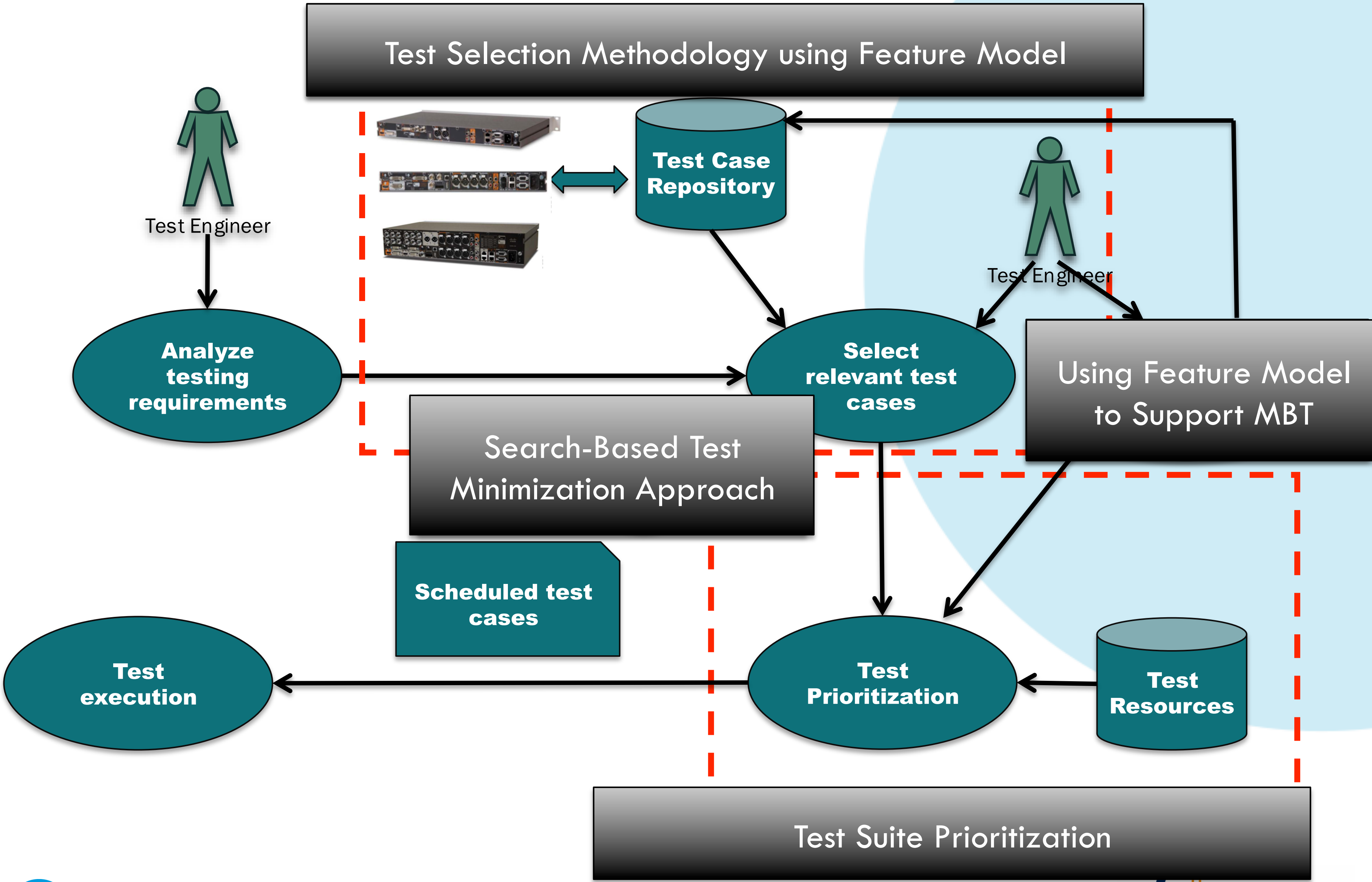
- ❑ Configure attributes CFM_B through the *Configuration Front-end*

- Wang, S., Ali, S.,Yue. T., Liaaen, M. **Using Feature Model to Support Model-Based Testing of Product Lines: An Industrial Case Study**. In: Proceedings of 13th International Conference on Quality Software (QSIC), pp. 75-84, 2013.

Evaluation: Industrial Case Study

- Industrial Case Study
  - C20
  - C40
  - C60
  - C90
- The complexity of configuration is reduced significantly
- The required modeling expertise is reduced

Research Problems



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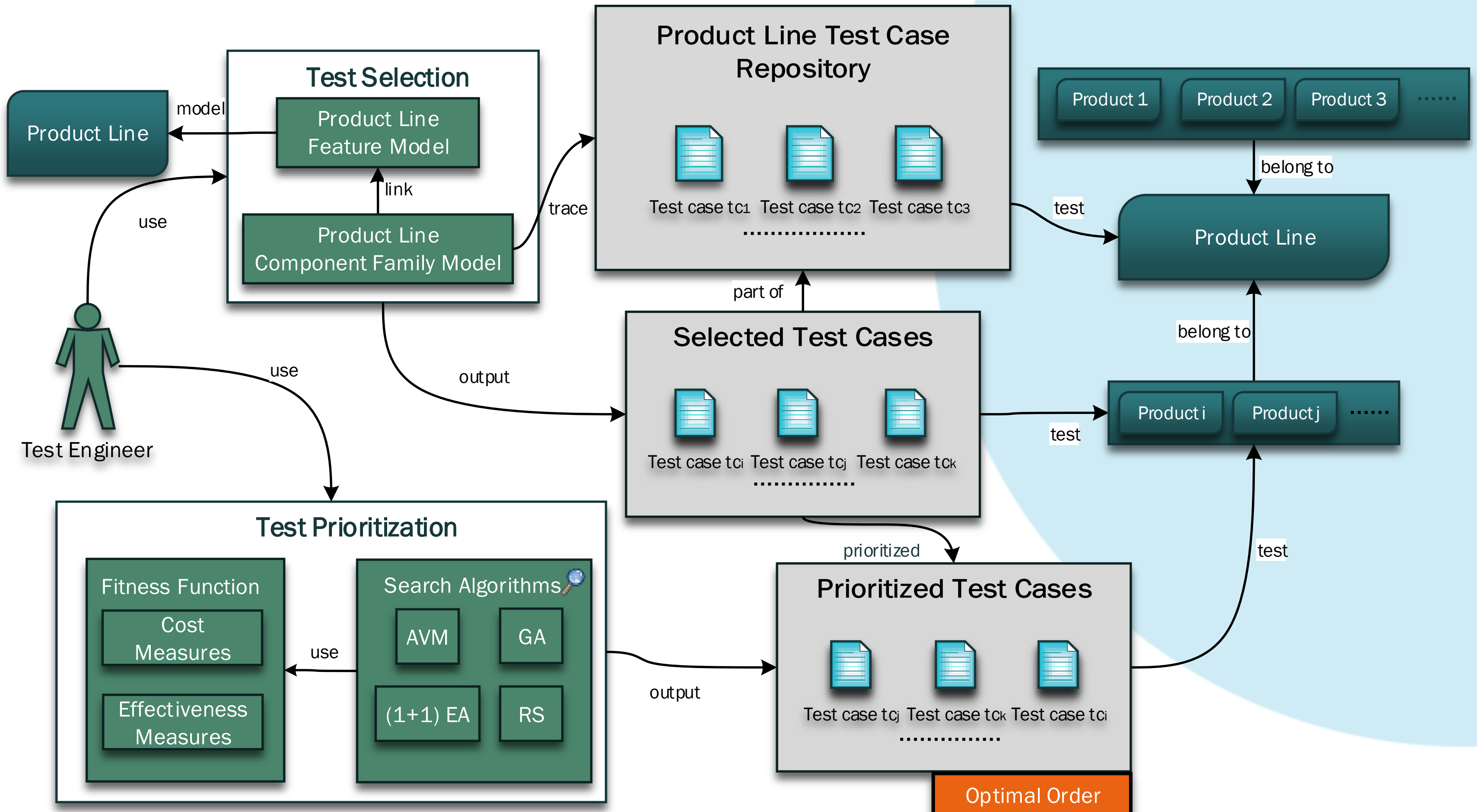
Test Prioritization:
Search-Based Test Prioritization Approach



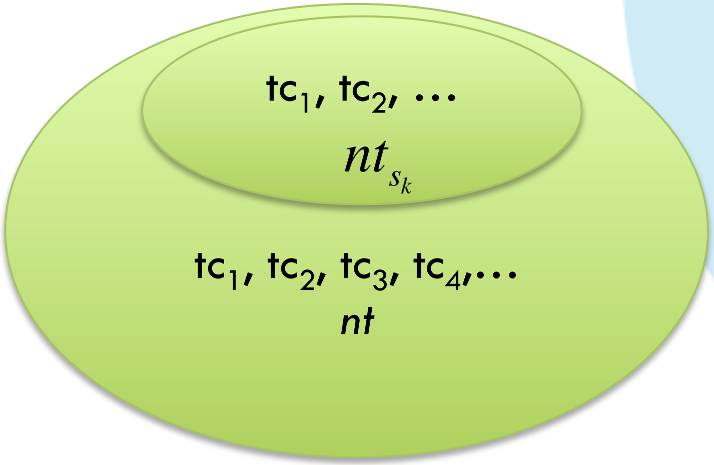
- S. Wang, S. Ali, T. Tue, Ø. Bakkeli, and M. Liaaen. Enhancing Test Case Prioritization in an Industrial Setting with Resource Awareness and Multi-Objective Search. In The 38th International Conference on Software Engineering (ICSE), Software Engineering in Practice (SEIP) track. pp. 182-191, 2016.
- Wang, S., Buchmann, D., Ali, A., Pradhan, D., and Liaaen, M. Multi-Objective Test Prioritization in Software Product Line Testing: An Industrial Case Study. In: Proceedings of 18th International Software Product Line Conference (SPLC 2014), **Best Paper Nominees**, pp. 32-41, 2014.

Cost-Effectiveness Measures

- Cost
  - Overall Execution Cost (*OEC*)
    - Measure the amount of time used for a solution
- Effectiveness
  - Prioritized Extent (PE)
    - Measure the extent of prioritization
  - Feature Pairwise Coverage (*FPC*)
    - Measure how many feature pairs can be covered
  - Fault Detection Capability (*FDC*)
    - Measure how many test cases in the solution can find faults

Effectiveness

- Prioritized Extent (PE)
  - Measure the extent of prioritization by a chosen solution



$$PE_{s_k} = \frac{nt_{s_k}}{nt}$$

Search Algorithms

$$Fitness\_P = 1 - w_1 * \left(1 - nor\ (OEC)\right) - w_2 * nor\ (PE) - w_3 * nor\ (FPC) - w_4\ * nor(FDC)$$

- Genetic Algorithm (GA)
- (1+1) Evolutionary Algorithm (EA)
- Alternating Variable Method (AVM)
- Random Search (RS)

Industrial Case Study and Artificial Problems

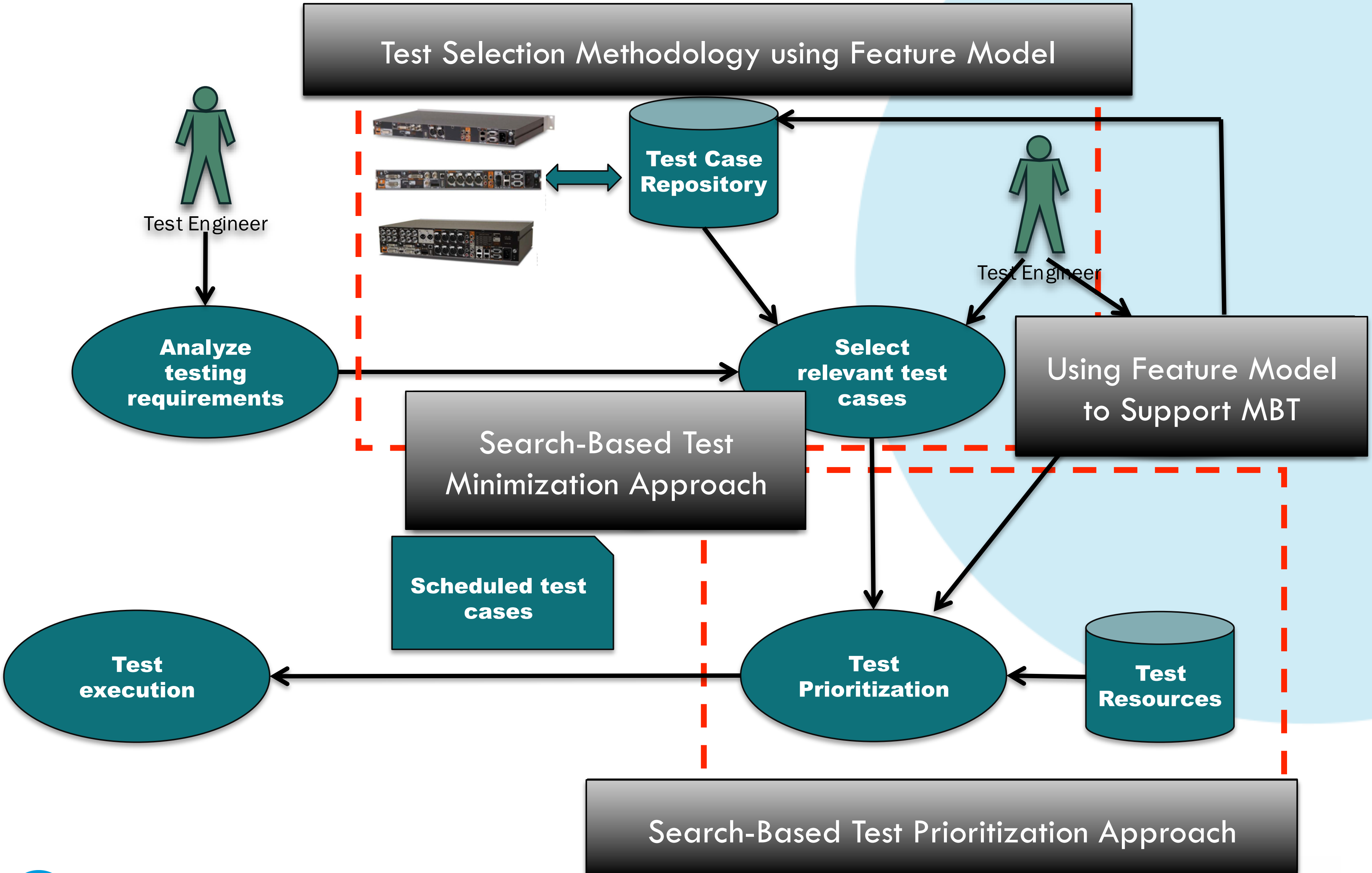
- *Saturn* product line: one testing cycle
  - 257 test cases
  - 53 features
  - 59 available resources

- 500 artificial problems
  - 3000 test cases
  - 600 features
  - 1000 available resources

Key Results for Evaluation

- Industrial Case Study
  - Search algorithms can achieve the acceptable level for test prioritization in terms of cost and effectiveness
  - (1+1) EA achieves the best performance among all the search algorithms
- 500 Designed Artificial Problems (Varying Complexity)
  - Similarly as industrial case study
  - Search algorithms can preserve high performance as the increasing complexity of problems

Conclusion


Test Selection Methodology using Feature Model
Test Engineer
Test Case Repository
Test Engineer
Analyze testing requirements
Select relevant test cases
Using Feature Model to Support MBT
Search-Based Test Minimization Approach
Scheduled test cases
Test execution
Test Prioritization
Test Resources
Search-Based Test Prioritization Approach

Thank You!
Questions?