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Software Testing with Evolutionary Strategies

Lenguajes y Ciencias de la Computación

UNIVERSIDAD DE MÁLAGA

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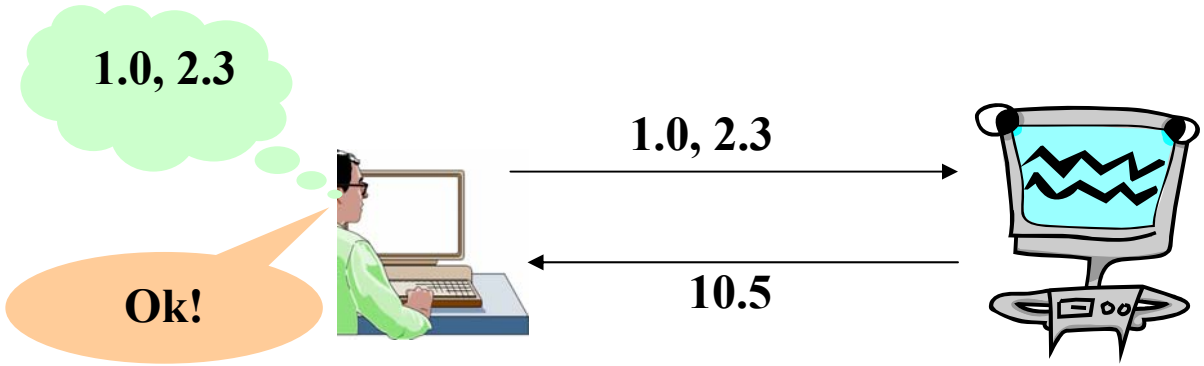
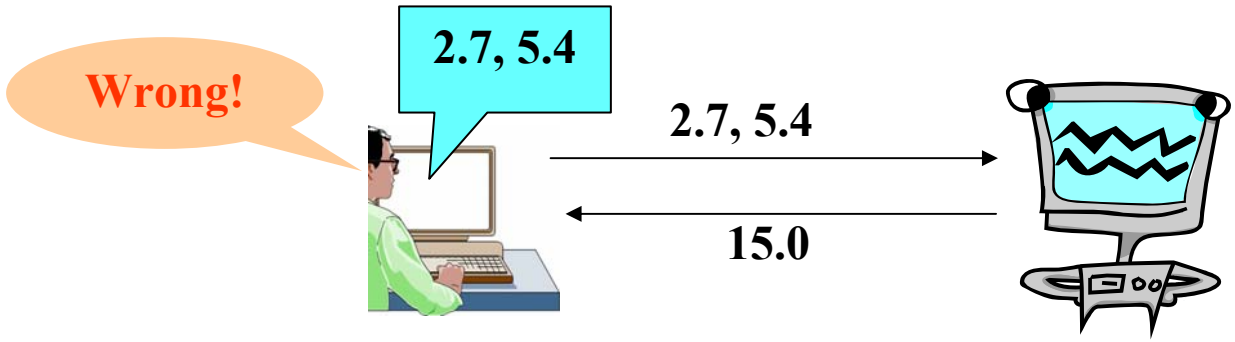
Introduction

- After codification, software products require a test phase
- The objective is to find errors and to ensure software correctness
- Software companies dedicate 50% of resources to this task



- We propose an automatic tool based on Metaheuristics to generate the input data for the test



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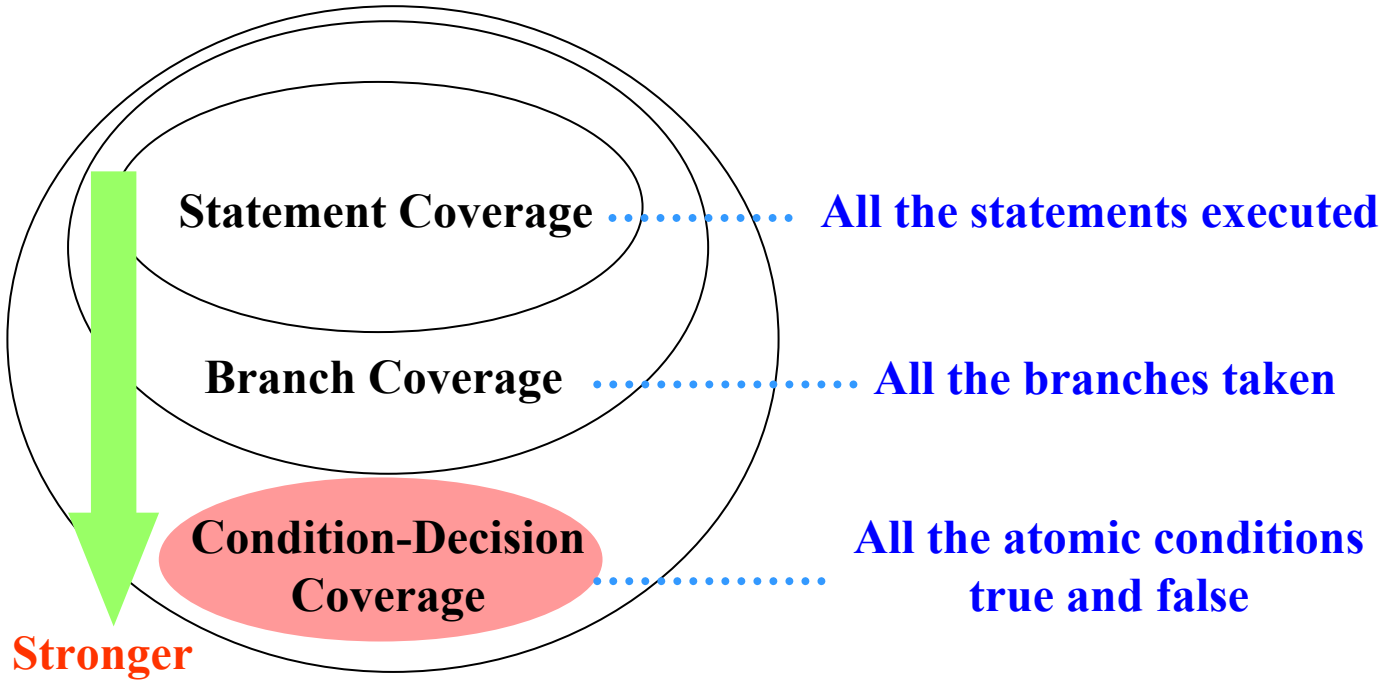
Test Adequacy Criteria

- Test data generator objective: to propose input data finding a maximum number of errors

Test Adequacy Criteria

- ~~Test data genera~~ **DIFFICULT TO CHECK** ~~ut data finding a maximum number of errors~~

- Test data generator objectives (test adequacy criteria)



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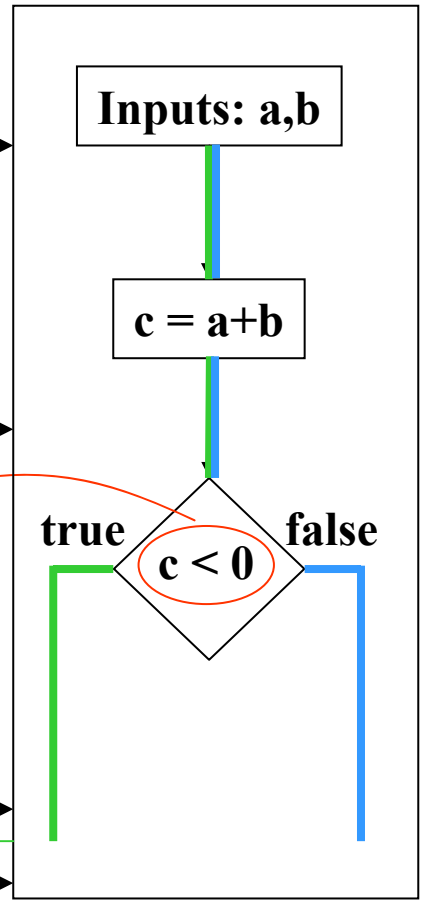
Previous Work

- **Three main paradigms:**
  - **Random test data generation**

1.2, 0.7



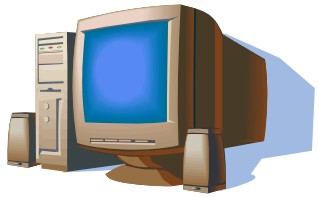
  - **Symbolic test data generation**

α, β

1.0, -2.0 ← α+β < 0

3.5, 1.2 ← α+β ≥ 0

  - **Dynamic test data generation**



-1.0, -0.5

1.0, -0.5

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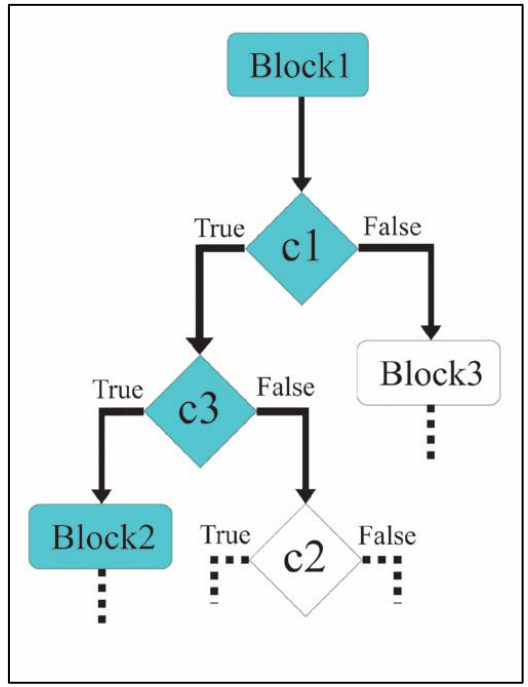
- The global objective is broken down in small sub-objectives

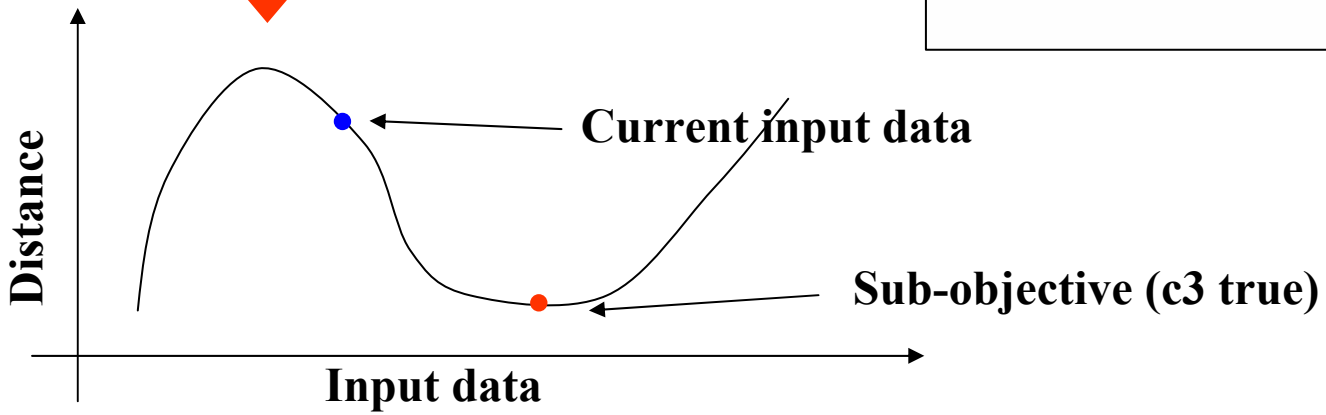
Six sub-objectives

c1 true c1 false
c2 true c2 false
c3 true c3 false

condition-decision coverage



Function minimization problem



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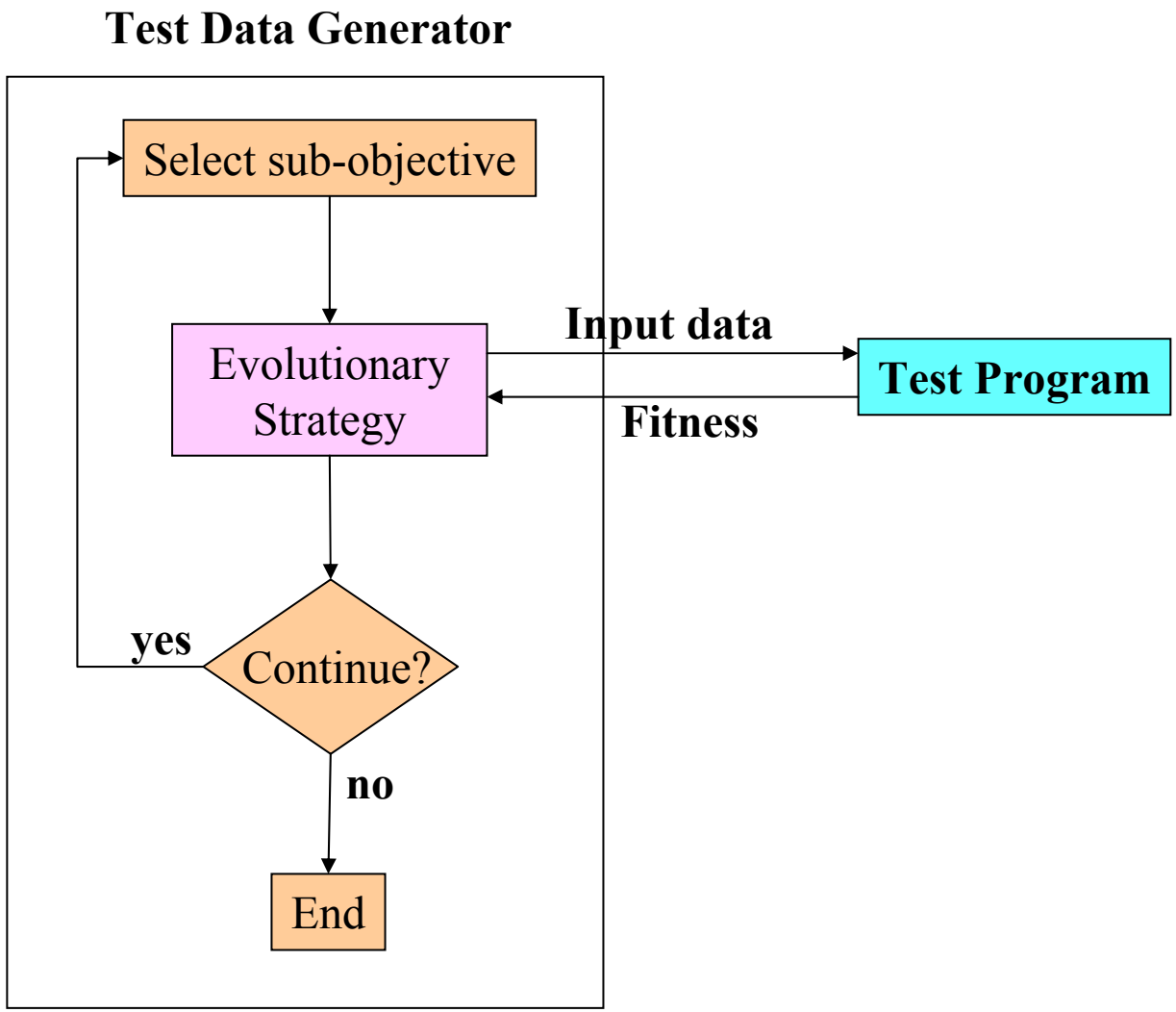
Test Data Generator



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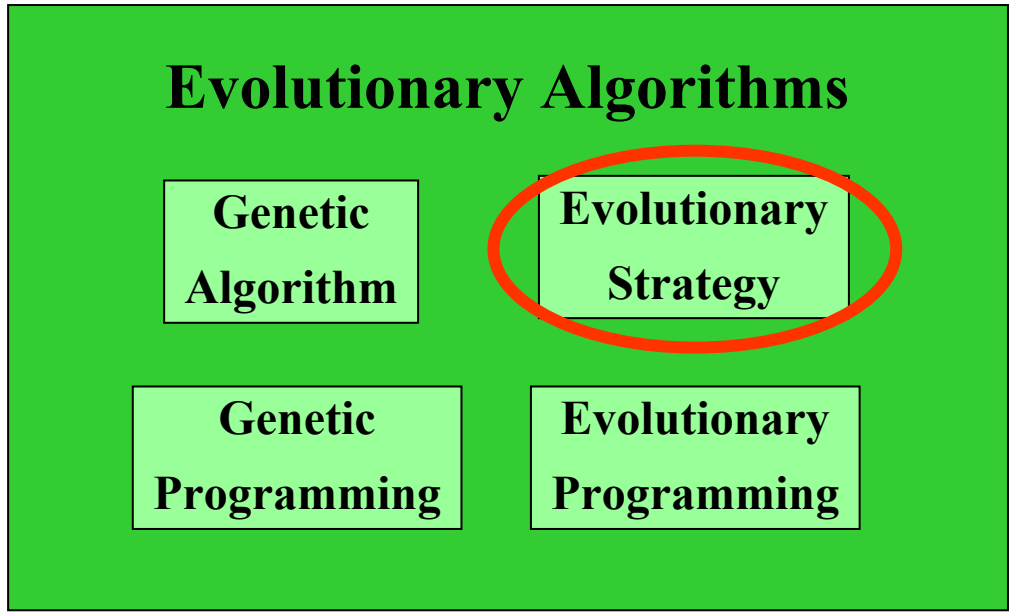
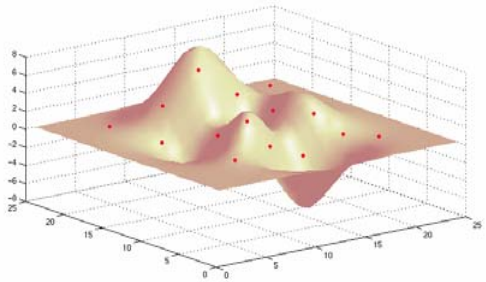
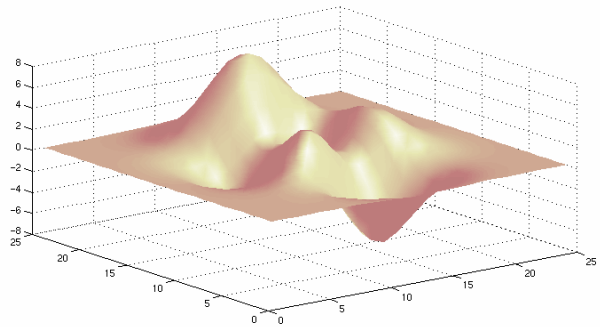


Population-based





Optimization problem

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Evolutionary Strategy

- **Pseudo-code of an Evolutionary Strategy**

```
t := 0;
P(0) := Generate();
Evaluate (P(0));
while stop criterion not met do
      P'(t) := Select (P(t));
      P''(t) := Gaussian_Mutation (P'(t));
      Evaluate(P''(t));
      P(t+1) := Replacement (P(t), P''(t));
      t := t+1;
end while;
return the best solution;
```

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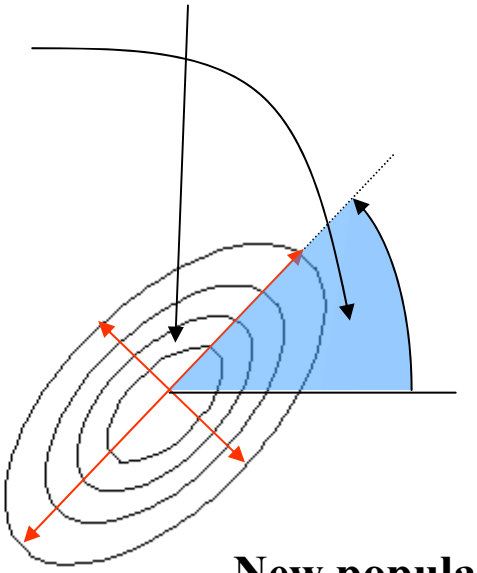
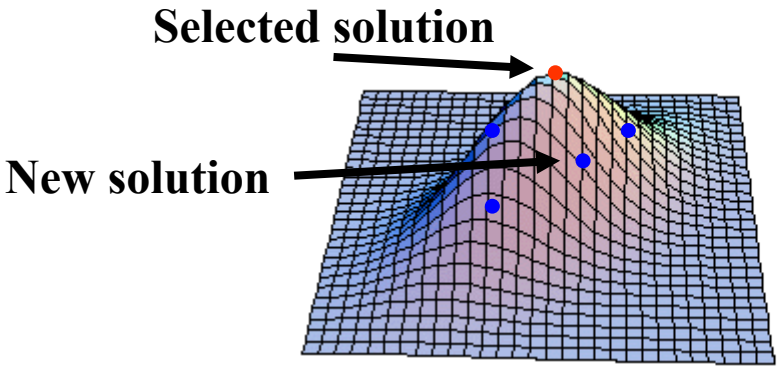
Evolutionary Strategy

- **Evolutionary Strategy**
  - **Individual**

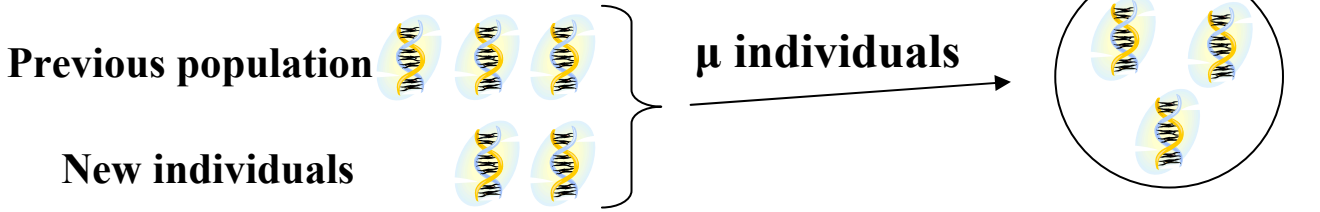
(0.2, -1.4, 3.5) → Solution vector
(1.0, 10.3, 7.2) → Standard deviations
(1.7, 0.3, 2.1) → Angles



  - **Gaussian Mutation**



  - **Replacement → (μ+λ) and (μ,λ)**



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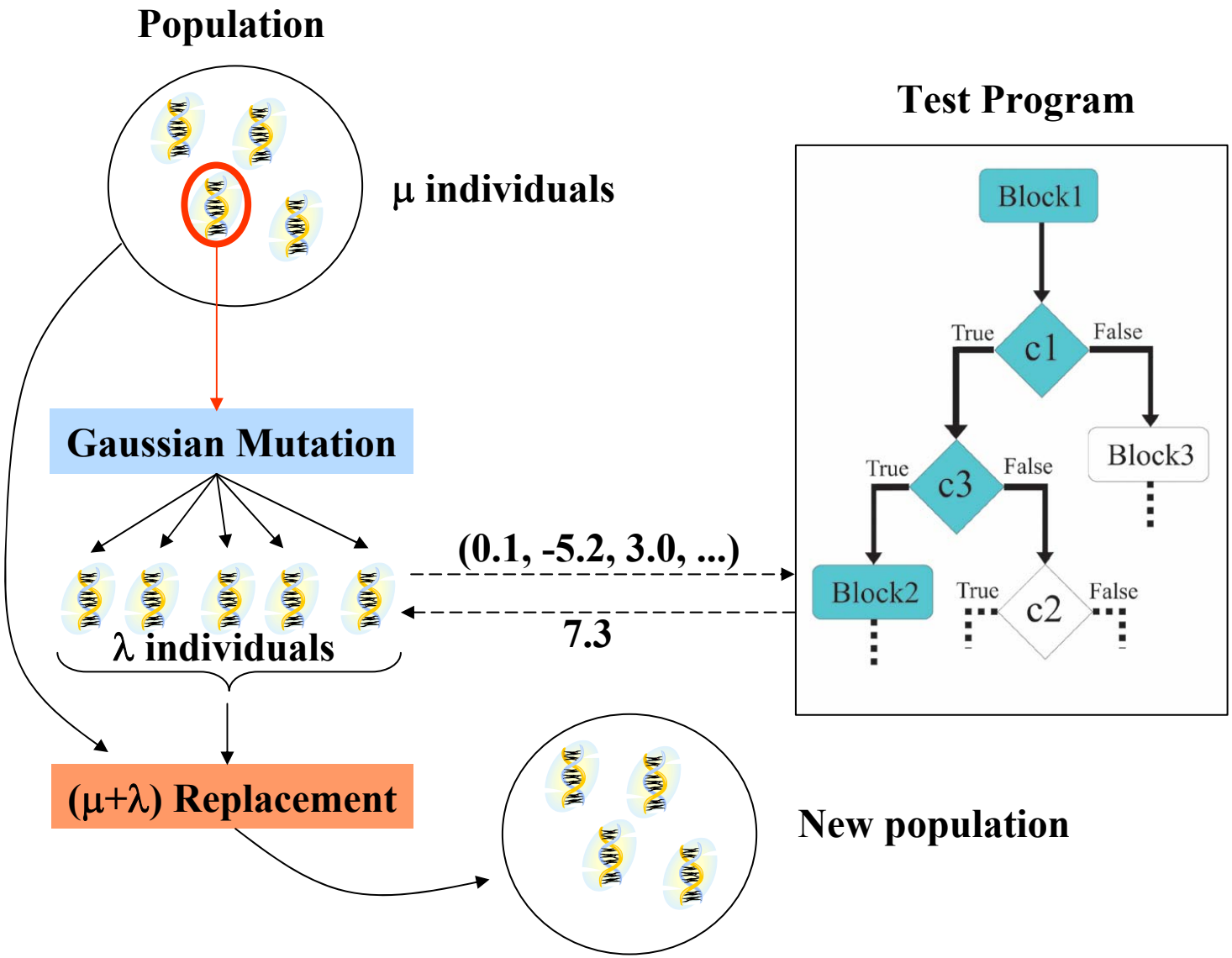

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Experiments: Benchmark

- **Benchmark: 11 programs in C language**

Program	Conds.	LOC	Args.	Source
triangle	21	53	3	Michael et al., 2001
gcd	5	38	2	Authors
calday	11	72	3	C-Recipes
crc	9	82	13	C-Recipes
insertion	5	47	20	C-Recipes
shell	7	58	20	C-Recipes
quicksort	18	143	20	C-Recipes
heapsort	10	72	20	C-Recipes
select	28	200	21	C-Recipes
bessel	21	245	2	C-Recipes
sa	30	332	23	C-Recipes

- **We perform 30 independent runs to get statistical confidence**

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Experiments: First Results

- Algorithm: (10+1)-ES
- Maximum iterations: 100

```
while(1<2)
{
    /* something */
}
```

Code-dependent coverage loss

```
p = malloc(4);
if (!p)
{
    error();
}
```

Environment-dependent coverage loss

Program	Avg. Cov.(%)	Avg. Evals.	Avg. Time(s)
triangle	97.54	1975	10.6
gcd	100.00	21	0.0
calday	91.82	1182	6.8
crc	94.44	1114	28.7
insertion	100.00	10	0.0
shell	100.00	10	0.0
quicksort	88.89	1110	8.4
heapsort	90.00	1110	9.4
select	53.57	1120	8.9
bessel	95.08	1306	7.6
sa	97.06	1329	5082.1

- Condition-decision is not a good metric for measuring accuracy

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Experiments: First Results

$$\text{Corrected coverage} = \frac{\text{reached sub-objectives}}{\text{reachable sub-objectives}}$$

(10+1)-ES		Corrected Coverage (%)		
Program	Cov.(%)	Avg.(%)	Max(%)	Std. Dev.
triangle	97.54	99.92	**100.00**	0.0044
gcd	**100.00**	**100.00**	**100.00**	0.0000
calday	91.82	91.82	**100.00**	0.0246
crc	94.44	**100.00**	**100.00**	0.0000
insertion	**100.00**	**100.00**	**100.00**	0.0000
shell	**100.00**	**100.00**	**100.00**	0.0000
quicksort	88.89	94.12	94.12	0.0000
heapsort	90.00	**100.00**	**100.00**	0.0000
select	53.57	83.33	83.33	0.0000
bessel	95.08	97.40	97.56	0.0061
sa	97.06	98.70	**100.00**	0.0072

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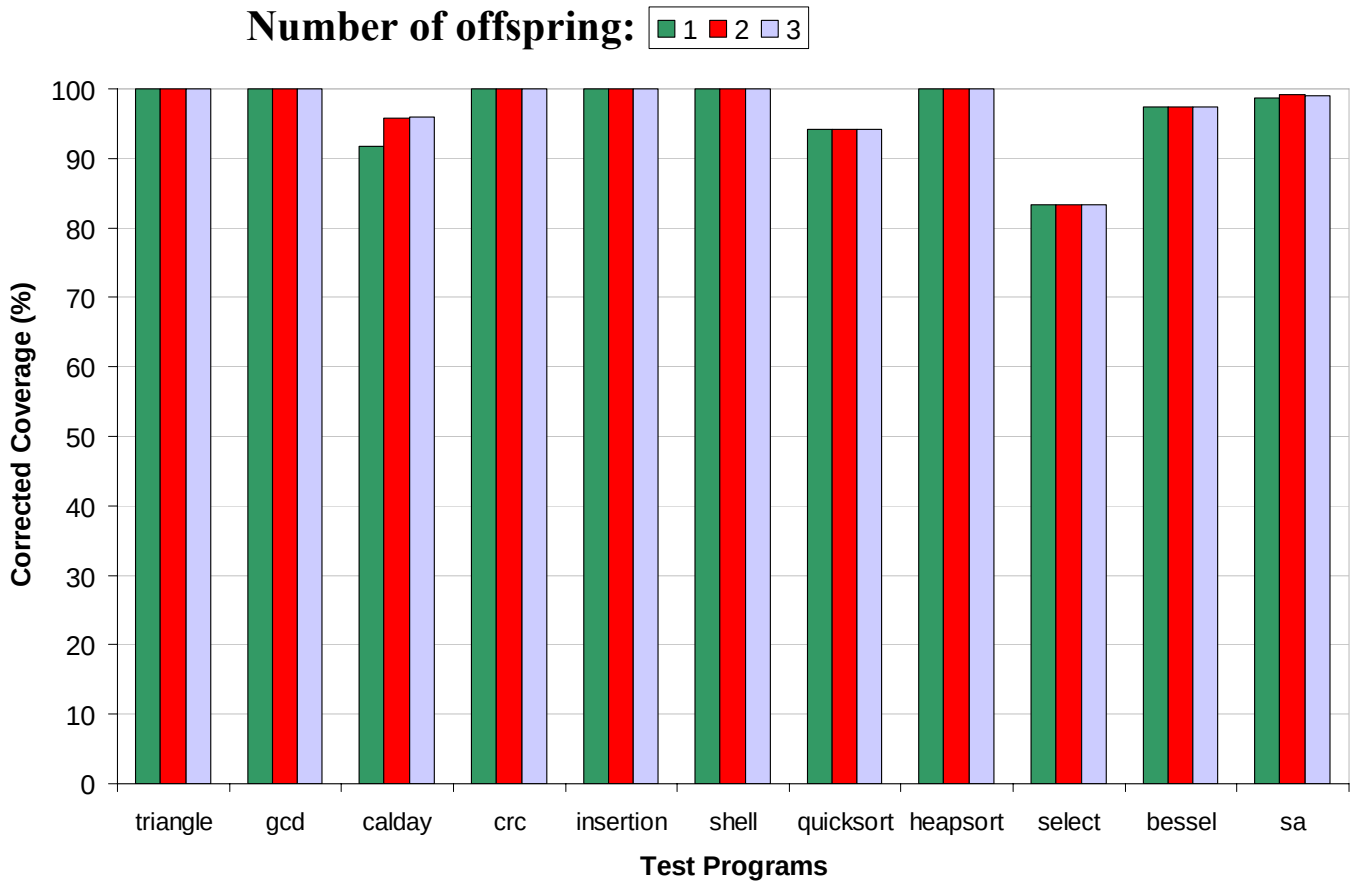
Experiments: Influence of λ



Influence of λ
- Coverage: negligible
- Number of evaluations: important

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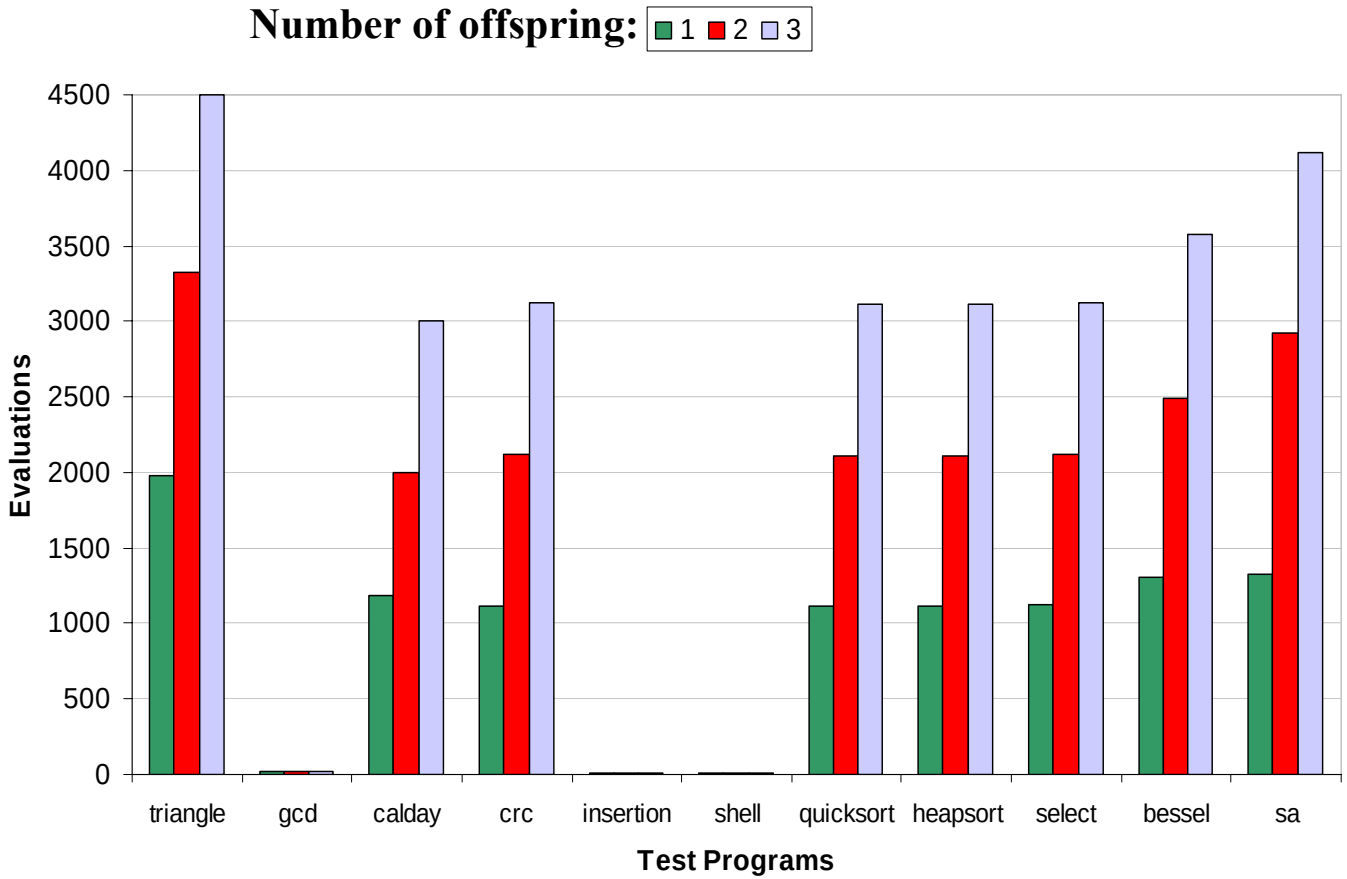
Experiments: Influence of λ



Influence of λ
- Coverage: negligible
- Number of evaluations: important

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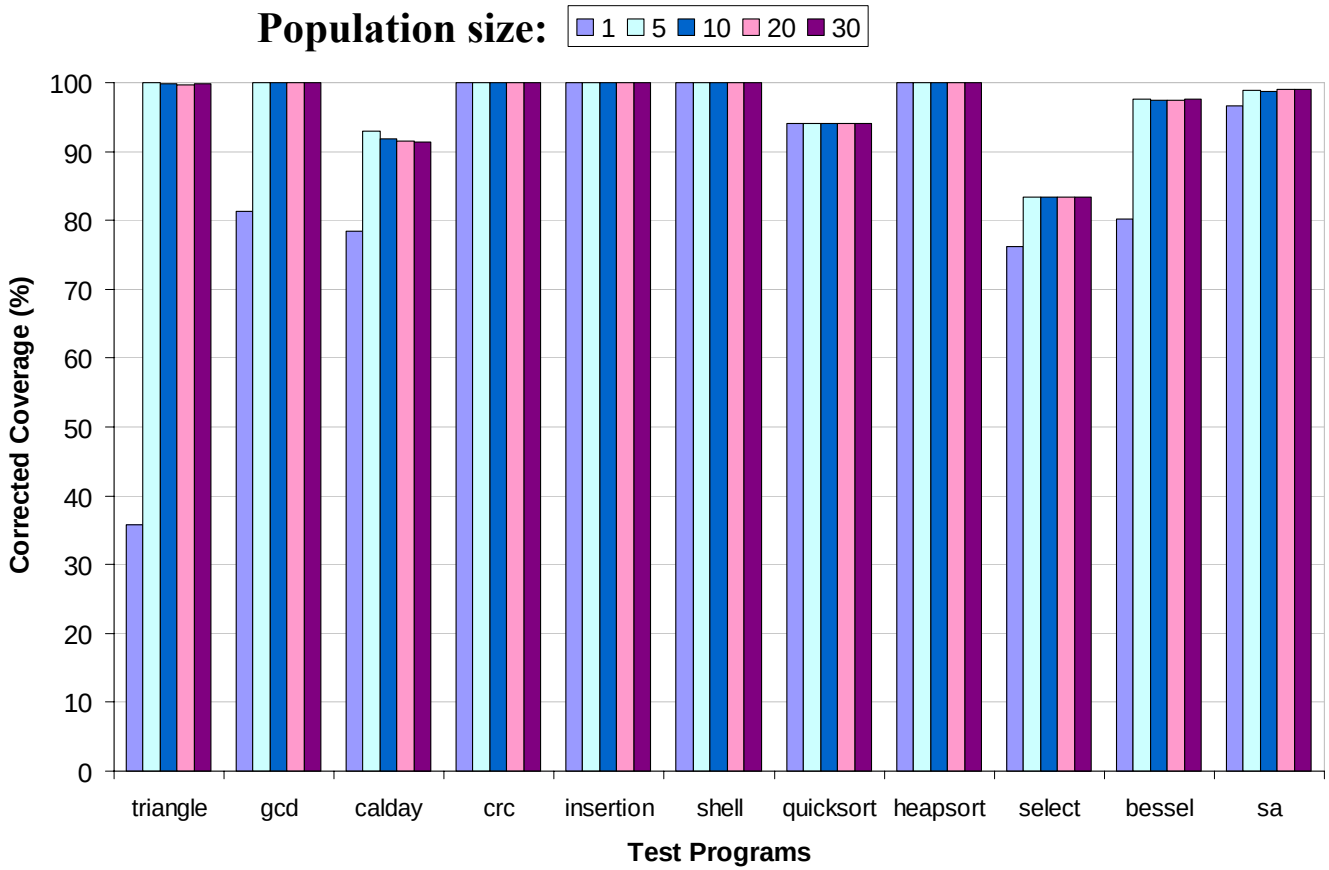
Experiments: Influence of μ



Influence of μ

- Coverage: negligible for $\mu \geq 5$
- Number of evaluations: slight

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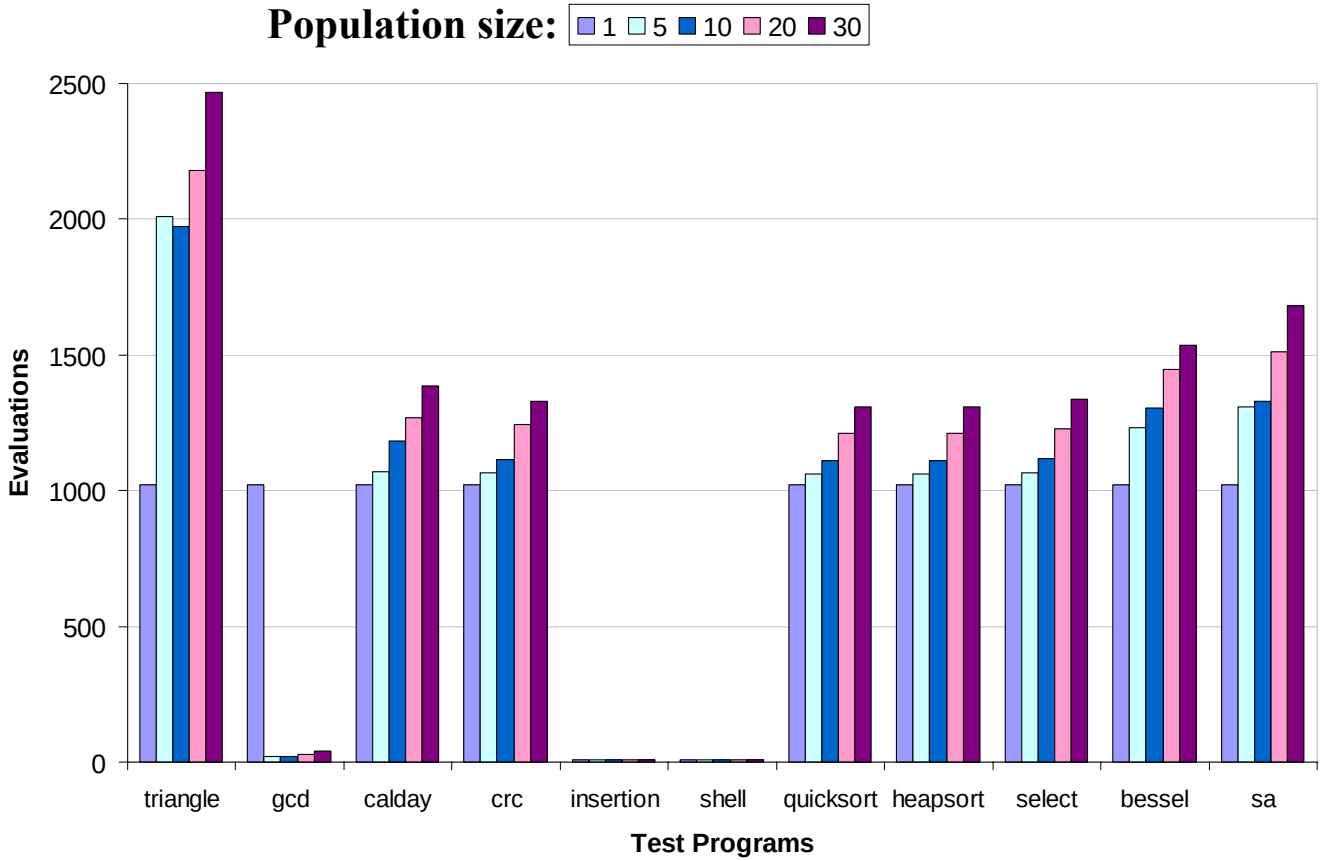
Experiments: Influence of μ



Influence of μ

- Coverage: negligible for $\mu \geq 5$
- Number of evaluations: slight

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Experiments: ES vs GA

	(10+1)-ES		(10+1)-GA	
Program	**Avg. Cov.(%)**	**Avg. Evals.**	**Avg. Cov.(%)**	**Avg. Evals.**
triangle	**99.92**	**1975**	95.20	2009
gcd	**100.00**	**21**	**100.00**	252
calday	**91.82**	**1182**	90.91	1217
crc	**100.00**	**1114**	**100.00**	1121
insertion	**100.00**	**10**	**100.00**	**10**
shell	**100.00**	**10**	**100.00**	**10**
quicksort	**94.12**	**1110**	**94.12**	**1110**
heapsort	**100.00**	**1110**	**100.00**	**1110**
select	**83.33**	**1120**	**83.33**	1339
bessel	**97.40**	**1306**	96.91	1557
sa	**98.70**	1329	96.61	**1110**

- **ES outperforms the results of the Genetic Algorithm**

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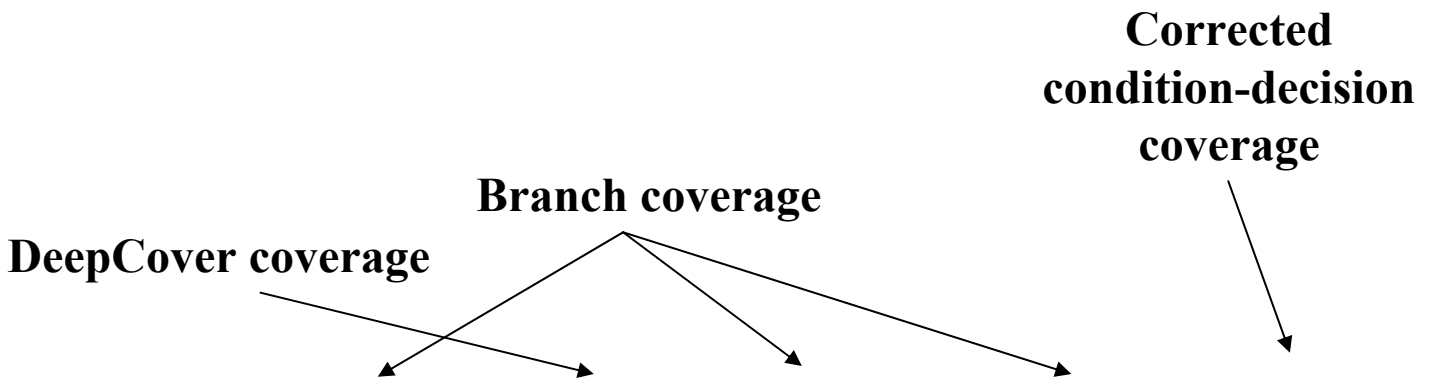
Experiments: Previous Results

- Two main issues to compare against different works:
  - The implementation → http://tracer.lcc.uma.es/problems/testing
  - The coverage measures



triangle	Jones et al.,1996	Michael et al., 2001	Sagarna et al., 2003	Sagarna et al., 2005	(5+1)-ES (this work)
Coverage(%)	100.00	94.29	100.00	100.00	100.00
Evaluations	18000	≈8000	608	3439	2010

- The (5+1)-ES gets total coverage with less number of evaluations (exception: Sagarna et al., 2003)

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Conclusions

- We propose a test data generator using an ES for software testing
- Condition-decision coverage is not a good measure of the generator accuracy → Corrected condition-decision coverage
- Increasing the number of offspring has a negligible impact in the coverage but it increases the number of evaluations needed
- The population size must be larger than one for a good coverage
- The ES-based test data generator outperforms the results of the GA-based one

Future Work

- Apply the test data generator to telecommunication software
- Use parallel evolutionary strategies
- Integrate some static analysis techniques

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THE END

Thanks for your attention !!!