Search-Based Software Project Scheduling

Francisco Chicano

joint work with E. Alba, A. Cervantes, D. González-Álvarez, F. Luna, A. J. Nebro, G. Recio, R. Saborido, M. A. Vega-Rodríguez

Introduction

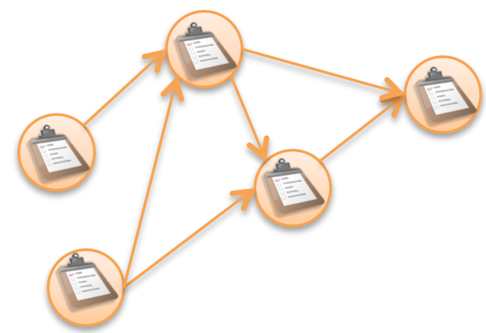
- Current software projects are very complex
- They can involve hundreds of people and tasks
- An efficient way of assigning employees to tasks is required
- An automatic software tool can assist to the software project manager
- Problem: assign employees to tasks with a given dedication degree

Employee

Salary
Maximum dedication
Skills

Task

Effort
Required skills
TPG



Introduction

- Several authors proposed different formulations in the literature

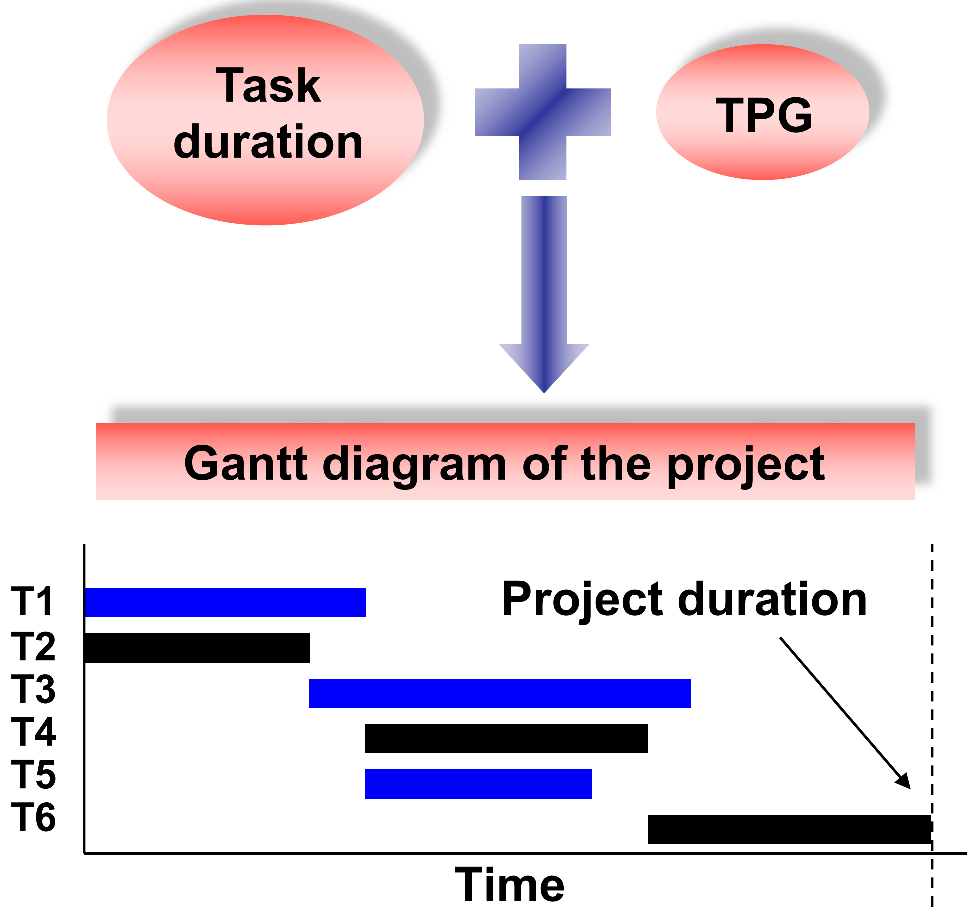
Basic Problem Formulation

Basic Problem Formulation: duration

- Project duration (computation)

	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0
E2	0.0	0.0	0.2	0.1	0.5	0.8
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0
	∑	**0.8**				

$$\frac{\textbf{Effort T2}}{\square} = \textbf{Duration T2}$$



Basic Problem Formulation: cost

- Project cost (computation)

	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5			
E2	Dur. T1 ×	Dur. T2 ×	Dur. T3 ×	Dur. T4 ×	Dur. T5 ×	Dur. T6 ×
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0

$\sum$ = time the employee spends on the project

Cost of employee E1 due to its participation

Cost of employee E2 due to its participation

Cost of employee E3 due to its participacion

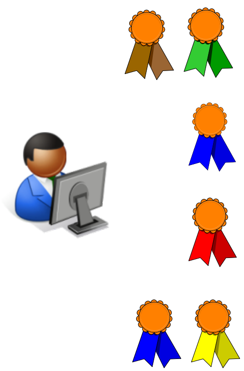
Cost of employee E4 due to its participacion

Time employee E3 spends on task T4

$\sum =$ **Project cost**

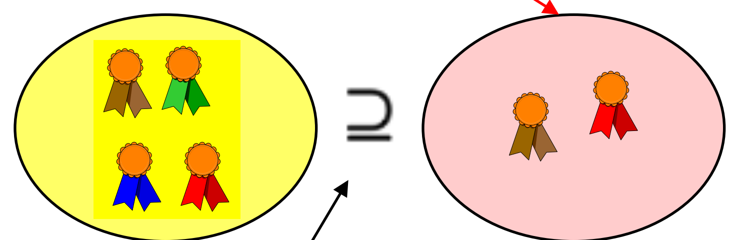
Basic Problem Formulation: constraints

- Constraints



	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0
E2	0.0	0.0	0.2	0.1	0.5	0.8
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0

$\sum$ **0.9** > 0



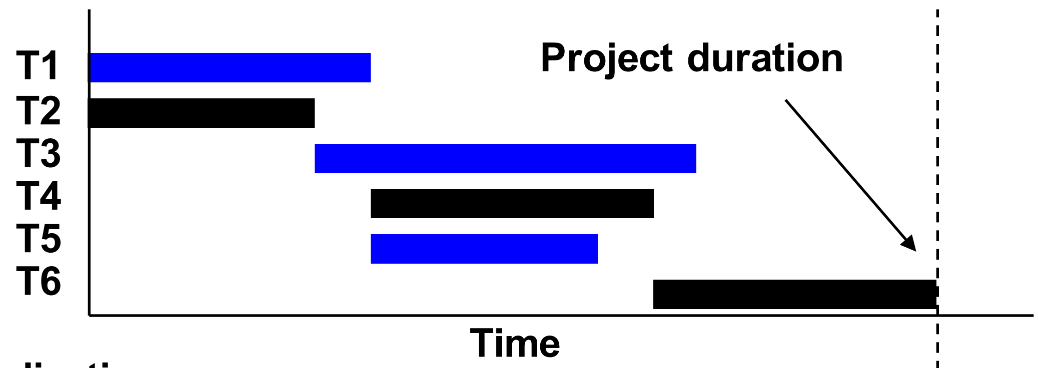
C1. All tasks must be performed

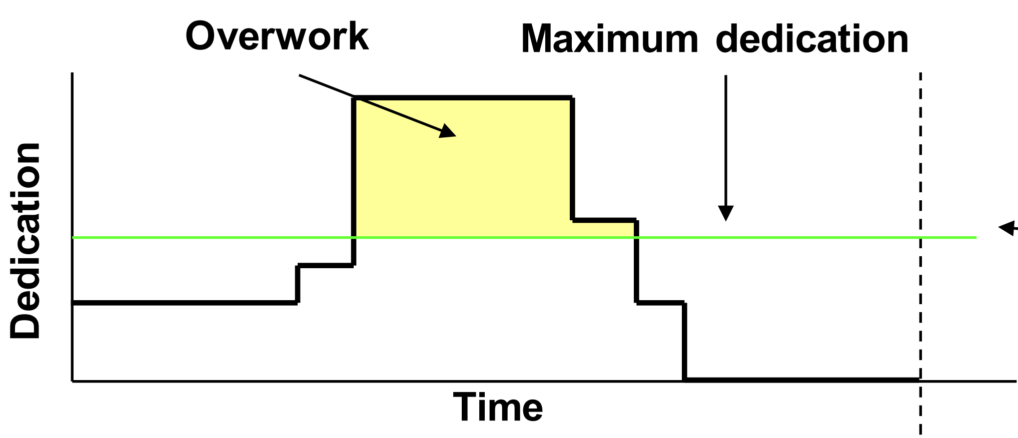
C2. The union of the work team skills must include the required skills of the task they perform

Basic Problem Formulation: constraints

- Constraints (cont.)

	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0





C3. No employee must exceed her/his maximum dedication

Basic Problem Formulation: fitness

$$f(\mathbf{x}) = \begin{cases} 1/q & \text{if the solution is feasible} \\ 1/(q+p) & \text{otherwise} \end{cases}$$

Peso	Valor
w_{cost}	10^{-6}
w_{dur}	0.1
w_{penal}	100
w_{undt}	10
w_{reqsk}	10
w_{over}	0.1

Project duration

$$q = w_{cost} \cdot p_{cost} + w_{dur} \cdot p_{dur}$$

Project cost

Overwork

$$p = w_{penal} + w_{undt} \cdot undt + w_{reqsk} \cdot reqsk + w_{over} \cdot p_{over}$$

Undone tasks

Required skills

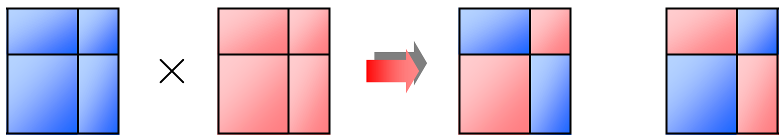
Basic Problem Formulation: algorithm & representation

- **Steady State GA** with binary representation
- **Maximum dedication** set to 1.0 for all employees → $x_{ij} \in [0,1]$
- **Matrix elements are discretized to eight values (3 bits per element)**

	T1	T2	T3	T4	T5	T6
E1	0,3	0,2	0,5	0,7	1,0	0,0
E2	0,0	0,0	0,2	0,1	0,5	0,8
E3	0,2	0,0	0,0	0,6	1,0	1,0
E4	0,4	0,6	0,0	0,0	0,0	1,0

	T1	T2	T3	T4	T5	T6
E1	010	001	100	101	110	000
E2	000	000	001	001	100	110
E3	001	000	000	100	111	111
E4	010	100	000	000	000	111

2D recombination



Chromosome

010001100101110000000000…

Basic Problem Formulation: experiments

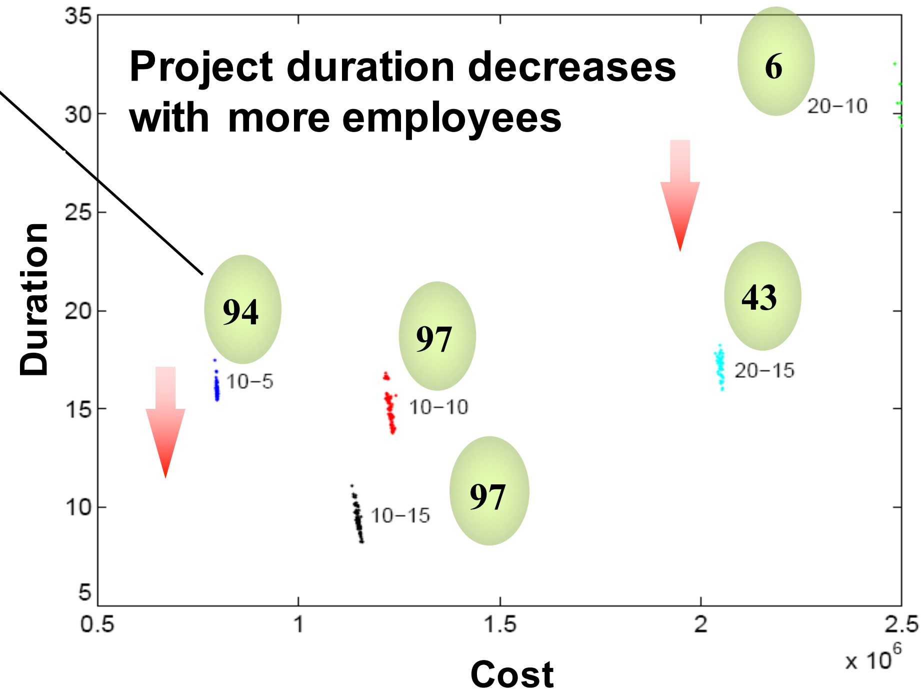
- **48 generated instances in 5 groups**
- **In the first three groups (12 instancias) only one parameter change**
  - ❖ **Employees (5, 10, 15, 20)**
  - ❖ **Tasks (10, 20, 30)**
  - ❖ **Skills of employees (2, 4, 6, 8, 10)**
- **Fourth and fifth groups: all parameters simultaneously change**
- **100 independent runs**

GA param.	Value
Population	64
Selection	Binary tournament
Recombination	2D crossover
Mutation	Bit flip (p_m=1/length)
Replacement	Elitist
Stop condition	5000 generations

Basic Problem Formulation: experiments

Fourth group of instances

Hit rate

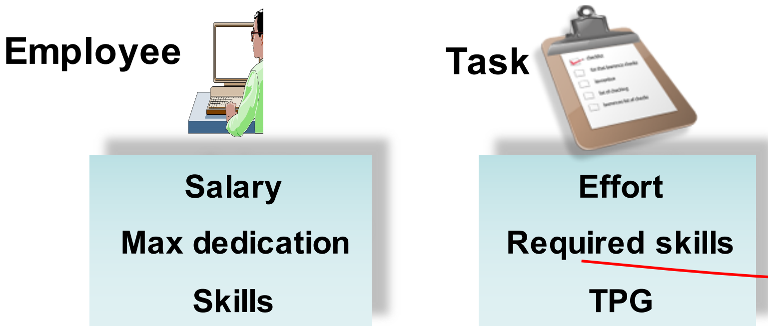


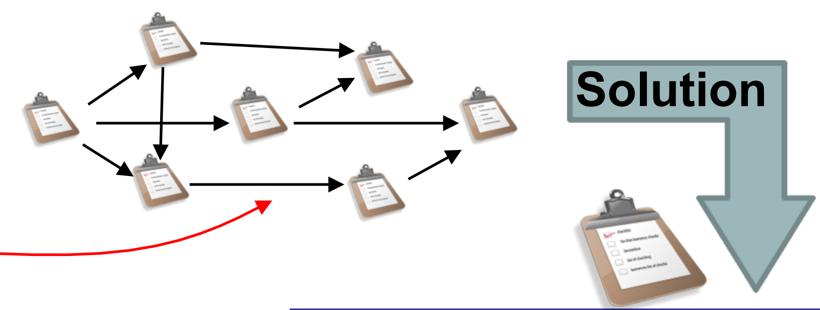
4-5 skills per employee

Multi-Objective Formulation

Multi-Objective Problem Formulation

- **Multi-Objective Software Project Scheduling**



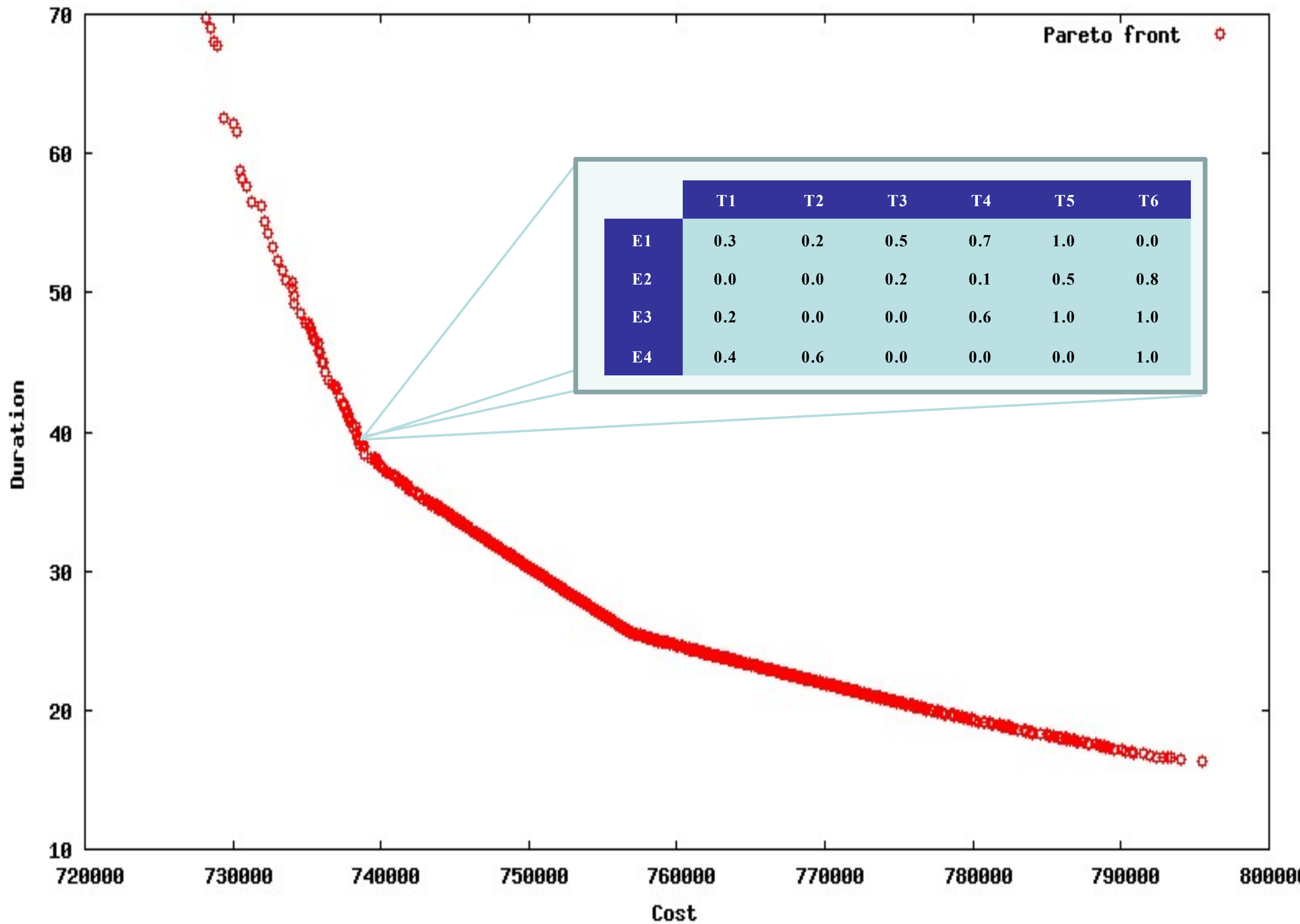


- Objectives
  - Minimize **the project cost**
  - Minimize **the project duration**
- Constraints
  - **C1: All tasks must be performed** by some employee
  - **C2**: The union of the employees skills must include the **required skills** of the task they perform
  - **C3**: No employee exceeds his/her **maximum dedication**

	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0
E2	0.0	0.0	0.2	0.1	0.5	0.8
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0

Dedication of E1 to T4

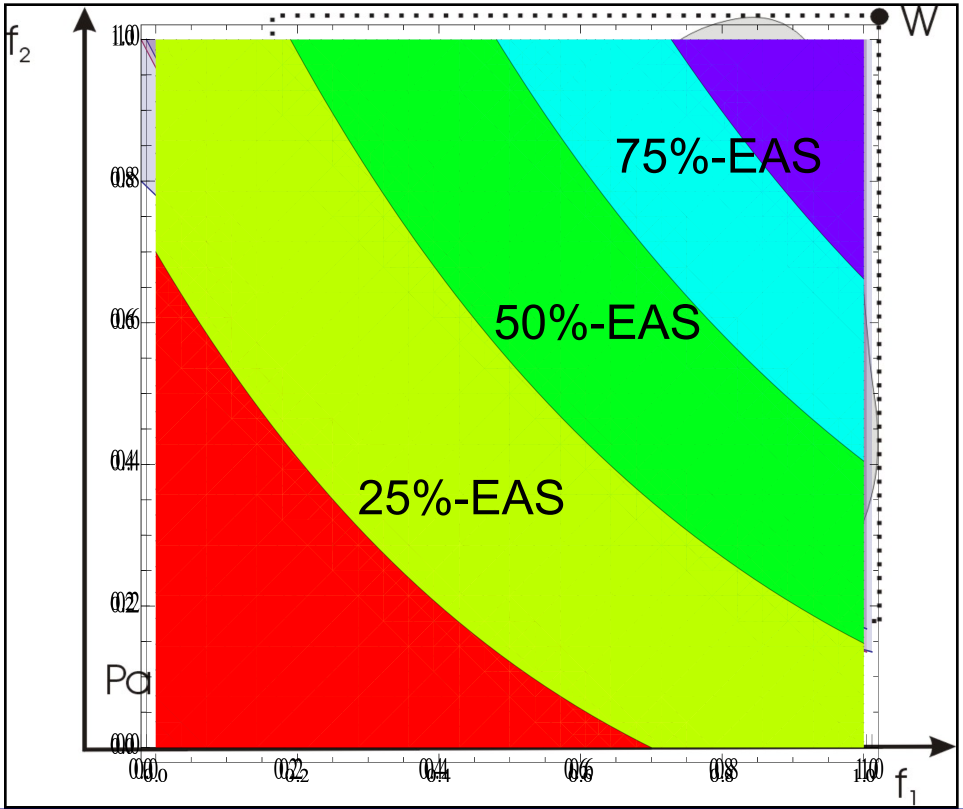
Multi-Objective Problem Formulation



	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0
E2	0.0	0.0	0.2	0.1	0.5	0.8
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0

Multi-Objective Problem Formulation: quality indicators

- Hypervolume (HV)
  - Volume covered by members of the non-dominated set of solutions
  - Measures both convergence and diversity in the Pareto front
  - Larger values are better
- Attainment surfaces
  - Localization statistics for fronts
  - The same as the median and the interquartile range in the mono-objective case



Multi-Objective Problem Formulation: algorithms

NSGA-II
- Generational GA
- Ranking & Crowding

SPEA2
- Generational GA + External Archive
- Strengh raw fitness & K-nearest neighbor

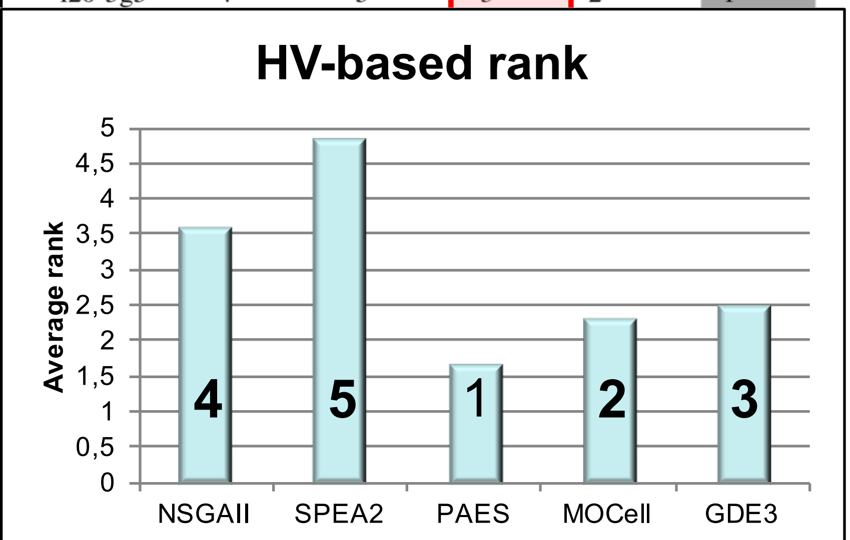
PAES
- (1+1) Evolution Strategy + External Archive
- Adaptive Grid

MOCell
- Cellular GA + External archive
- Ranking & Crowding from NSGA-II

GDE3
- Differential Evolution
- Ranking & NSGA-II's improved crowding

Multi-Objective Problem Formulation: results

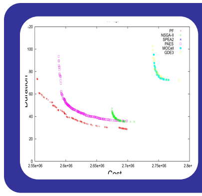
Instances	Algorithms				
	NSGAII	SPEA2	PAES	MOCell	GDE3
i10-5g5	4	5	3	1	2*
i10-5g10	3	5	4	1	2*
i10-10g5	4	5	1	3*	2*
i10-10g10	4	5	3	1	2*
i10-15g5	4	5	1	3	2
i10-15g10	4	5	1	3*	2*
i20-5g5	4	5	3*	2*	1
i30-15p5	3.5	3.5	1	3.5	3.5
i10-5p7	3	5	4	1	2*
i20-5p7	4	5	3	1	2*
i30-5p7	4	5	1	2	3
i10-10p7	4	5	3	1	2*
i20-10p7	4	5	1	3	2
i30-10p7	4	5	1	2	3
i10-15p7	4	5	3*	2*	1
i20-15p7	4	5	1	3	2
i30-15p7	3.5	3.5	1	3.5	3.5



- **Ranking** of the algorithms based on the **median** of their HV values
- **PAES** has reached the approximated fronts with the **better (higher) HV**
  - Best in **25** out of 36 instances
  - It assigns a **low dedication to employees** → avoid constraint violation for larger instances
- **MOCell** and **GDE3** performs specially well for **small instances**
- Neither **NSGA-II** nor **SPEA2** have ranked the first nor second for any instance
- **Crossover operators** (in NSGA-II, SPEA2, and MOCell) and **Differential Evolution recombination** (in GDE3) generate many **unfeasible solutions** in large instances

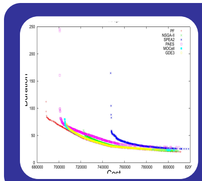
Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV



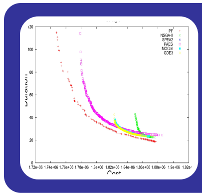
Scenario 1

- PAES outperforms all the others
- Project plans with low cost and long durations



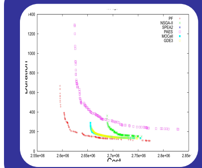
Scenario 2

- All the algorihtms perform the same
- But SPEA2



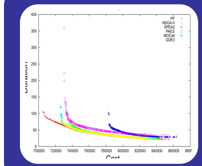
Scenario 3

- The attainment surfaces of NSGA-II, MOCell, and GDE3 cross that of PAES
- PAES is slightly worse in concrete regions



Scenario 4

- PAES fails at reaching short but costly projet plans
- Its HV remains the higher because of its extension

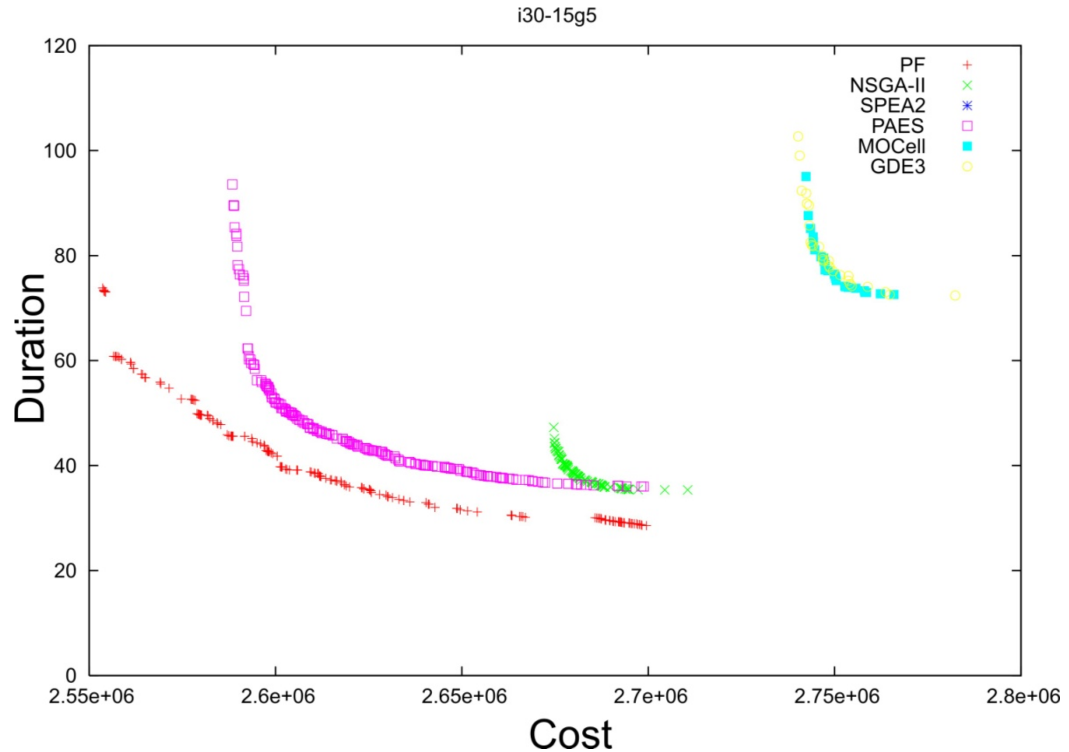


Scenario 5

- PAES is clearly outperformed
- It happens in the smaller (easier) instances

Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV

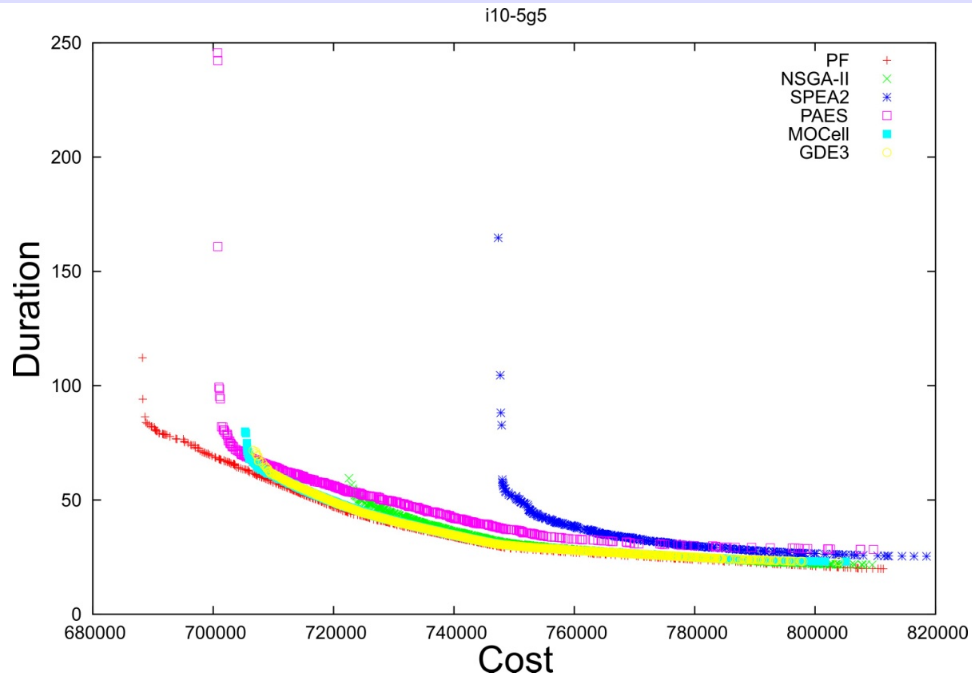


Scenario 1

- **PAES clearly dominates the solutions reached by all the other algorithms**
- **This algorithm has also reached project plans with low cost and long durations**

Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV

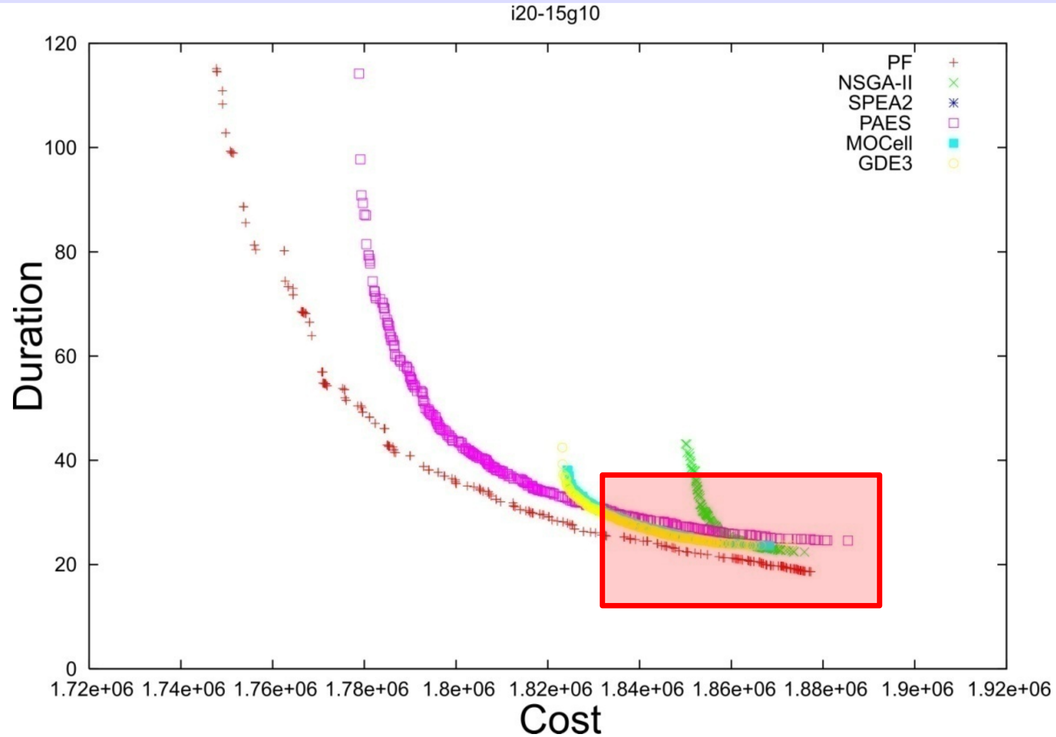


Scenario 2

- **All the algorithms but SPEA2 perform the same**
- **On average, their approximated fronts are overlapped in almost the entire objective space**
- **They are also very close to the reference Pareto Front (PF)**

Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV

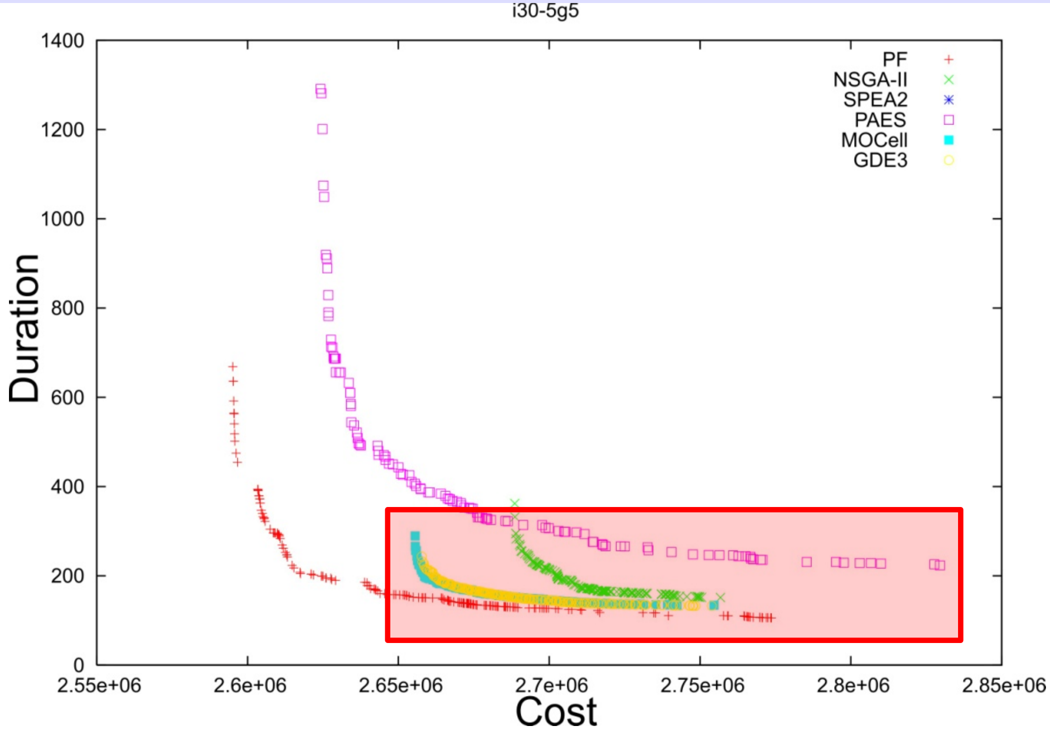


Scenario 3

- **The attainment surfaces of NSGA-II, MOCell, and GDE3 cross that of PAES → the region of project plans with short durations and high cost**
- **PAES still obtains the best HV values because it covers a larger portion of the objective space**

Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV

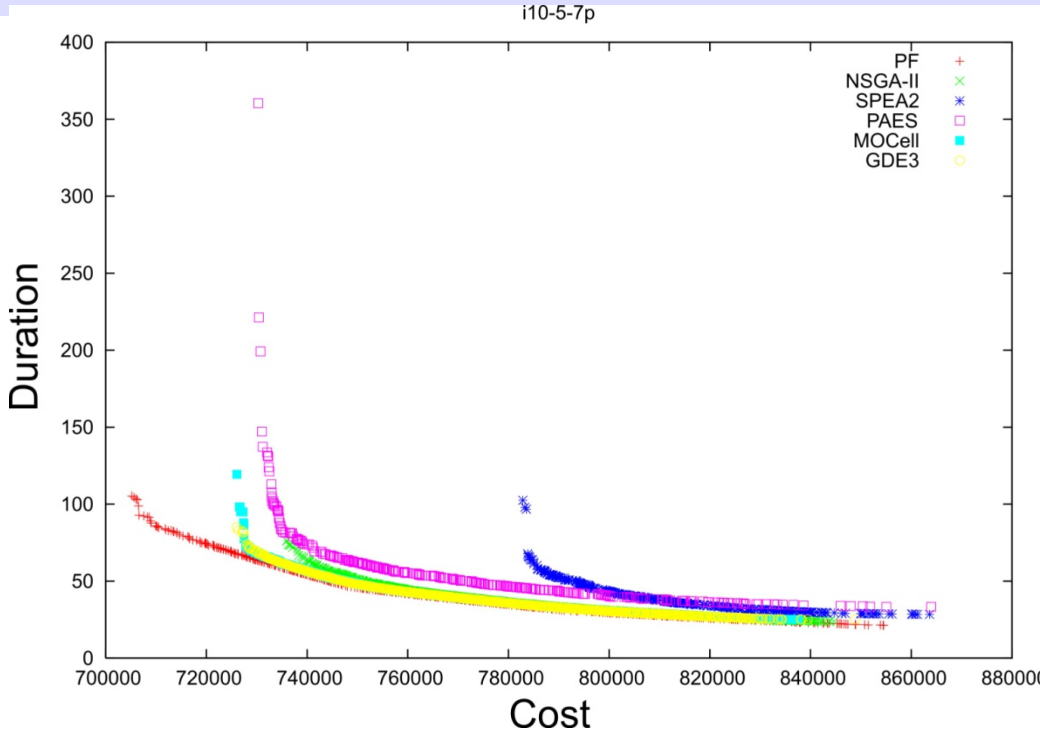


Scenario 4

- **PAES is clearly the worse algorithm at reaching project plans with short durations and high cost**
- **This happens in 18 out of the 36 instances**
- **PAES still gets the best HV value → Is HV suitable to make decisions?**

Multi-Objective Problem Formulation: results

- They graphically represent the median
- PF is the reference Pareto Front build for each instance
- They clearly explain the high HV values of PAES
- Five different behaviors remain hidden to a scalar indicator such as HV



Scenario 5

- **NSGA-II, MOCell and GDE3 clearly dominates the attainment surface of PAES**
- **The HV values now reflect this fact**
- **It always happens in the smaller (easier) instances**

Multi-Objective Problem Formulation: results

- **Spearman rank correlation coefficients** of the solutions in an approximat...

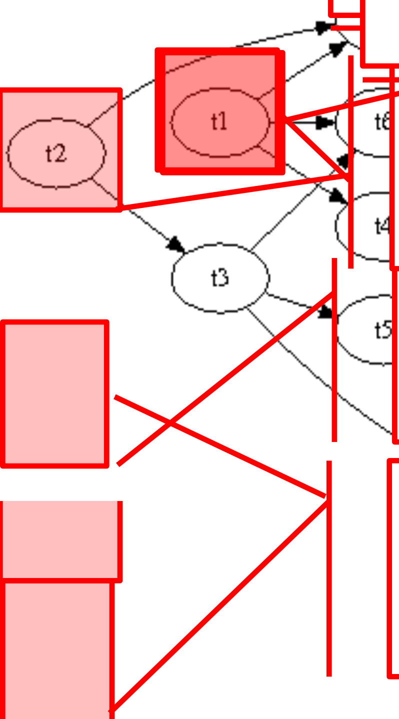
The workload is increased in t1 and ...

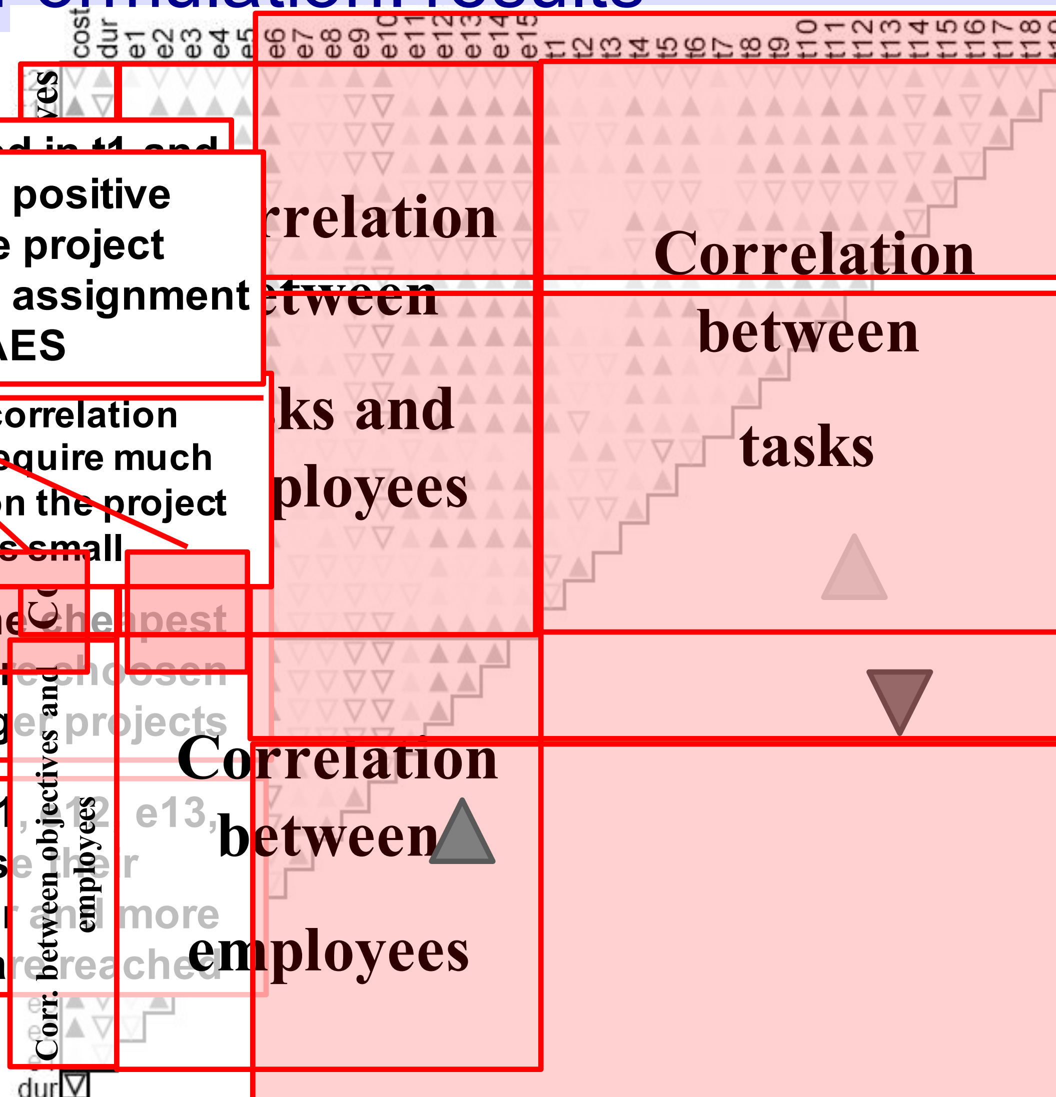
t14, t16 and t20 has positive correlation with the project duration → not optimal assignment reached by PAES

t1 and t2: negative correlation because t2 does not require much effort so its influence on the project cost or duration is small

e7, e8, e9, e10 are the cheapest employees → they are choosen for cheaper and longer projects

e2, e3, e4, e5, e6, e11, e12, e13, e14 , e15 increase their dedication as shorter and more expensive projects are reached



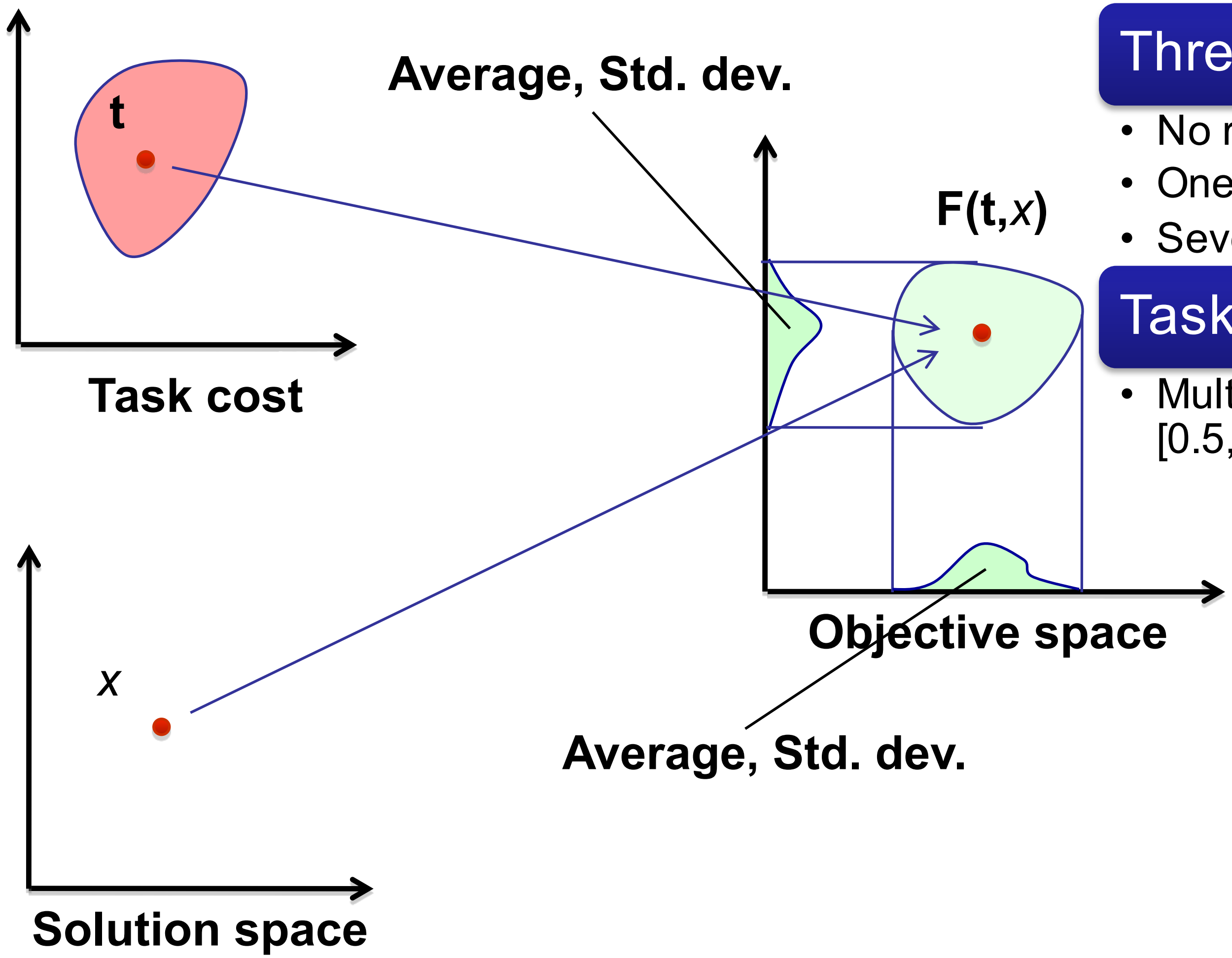


Second (and Robust) Formulation

Motivation for the Second Formulation

- The problem formulation is far from realistic:
  - Task effort is not an exact value (as assumed), we can only estimate it
  - Skills are not 0 or 1, there are degrees
  - Durations are not real values, they are discrete
- How to model:
  - Task effort inaccuracy ▸ robust optimization
  - Non-binary skills ▸ productivity matrix
  - Discrete durations ▸ discrete event simulator

Robustness



Three approaches

- No robustness (NR)
- One task changes (OTR)
- Several tasks change (STR)

Task change

- Multiply by a random value in [0.5,2]

Instance Information

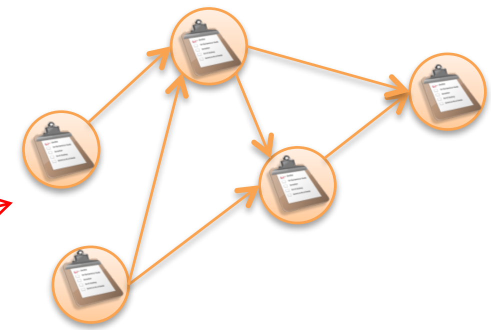
Employee

Salary

Task

Cost

TPG



Productivity matrix

	T1	T2	T3	T4	T5	T6
E1	0.3	0.2	0.5	0.7	1.0	0.0
E2	0.0	0.0	0.2	0.1	0.5	0.8
E3	0.2	0.0	0.0	0.6	1.0	1.0
E4	0.4	0.6	0.0	0.0	0.0	1.0

Solution

Priorities matrix

q	T1	T2	T3	T4	T5	T6
E1	3	1	5	0	0	0
E2	0	0	2	1	5	0
E3	2	0	0	0	1	1
E4	0	0	0	1	0	1

d
0.3
1.0
0.2
0.4

Dedication vector

Delays vector

r	3	2	5	7	1	0

- **The evaluation of a solution is based on a simulation of the project**
- **Objectives:**
  - **Makespan: the minimum time slot in which all tasks are done**
  - **Cost: salary multiplied by the dedication and worked hours**

Algorithms in the Comparison

NSGA-II
- Generational GA
- Ranking & Crowding

SPEA2
- Generational GA + External Archive
- Strengh raw fitness & K-nearest neighbor

PAES
- (1+1) Evolution Strategy + External Archive
- Adaptive Grid

MOCell
- Cellular GA + External archive
- Ranking & Crowding from NSGA-II

Experiments: Instances

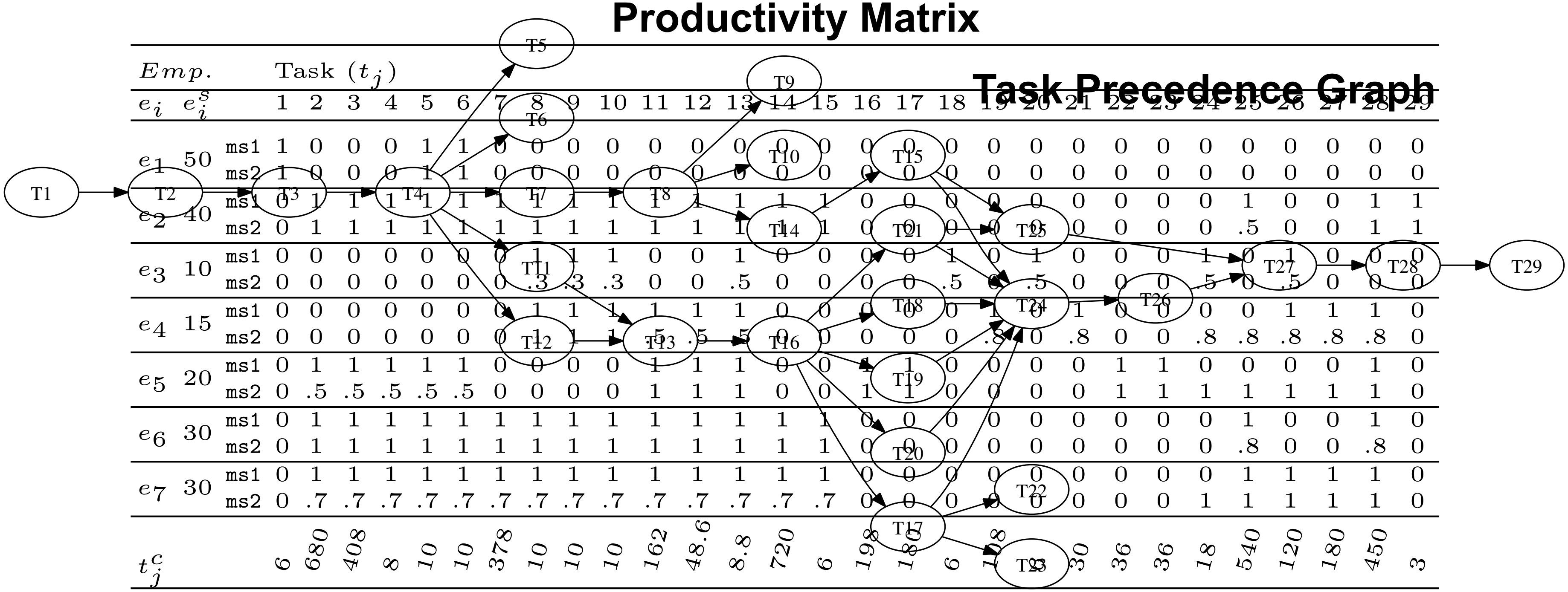
Problem instances

- 2 instances based on a MS Project repository real example: ms1 and ms2

Productivity Matrix

$Emp.$ e_i	e_i^s		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
e_1	50	ms1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		ms2	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
e_2	40	ms1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	1
		ms2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	.5	0	0	1	1
e_3	10	ms1	0	0	0	0	0	0	0	1	1	1	0	0	1	0	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
		ms2	0	0	0	0	0	0	0	.3	.3	.3	0	0	.5	0	0	0	0	.5	0	.5	0	0	0	.5	0	.5	0	0	0
e_4	15	ms1	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1	0	1	0	0	0	0	1	1	1	0
		ms2	0	0	0	0	0	0	0	1	1	1	.5	.5	.5	0	0	0	0	0	.8	0	.8	0	0	.8	.8	.8	.8	.8	0
e_5	20	ms1	0	1	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	0
		ms2	0	.5	.5	.5	.5	.5	0	0	0	0	1	1	1	0	0	1	1	0	0	0	0	1	1	1	1	1	1	1	0
e_6	30	ms1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0
		ms2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	.8	0	0	.8	0
e_7	30	ms1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	1	0
		ms2	0	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	.7	0	0	0	0	0	0	0	0	1	1	1	1	1	0
t_j^c			6	680	408	8	10	10	378	10	10	10	162	48.6	8.8	720	6	198	180	6	108	[illegible]	30	36	36	18	540	120	180	450	3

Task Precedence Graph



Experiments: Algorithm-Specific Parameters

NSGAII	SPEA2	PAES	MOCell
Population: 100	Population: 100	Population: 1	Population: 100
Binary tournament	Binary tournament		Binary tournament
DPX (p_c=0.9)	DPX (p_c=0.9)		DPX (p_c=0.9)
Uniform mutation (p_m=1/L)	Uniform mutation (p_m=1/L)	Uniform mutation (p_m=1/L)	Uniform mutation (p_m=1/L)

Experiments: Global Parameters

Global Parameters

- Stopping condition: 1 000 000 function evaluations
- Approximated Pareto front size: 100 solutions
- Sampling H=100
- 100 independent runs for each algorithm-instance
- Statistical tests for significance differences (95%)
- Representation: integer matrix + real vector + integer vector

Results: Hypervolume Comparison

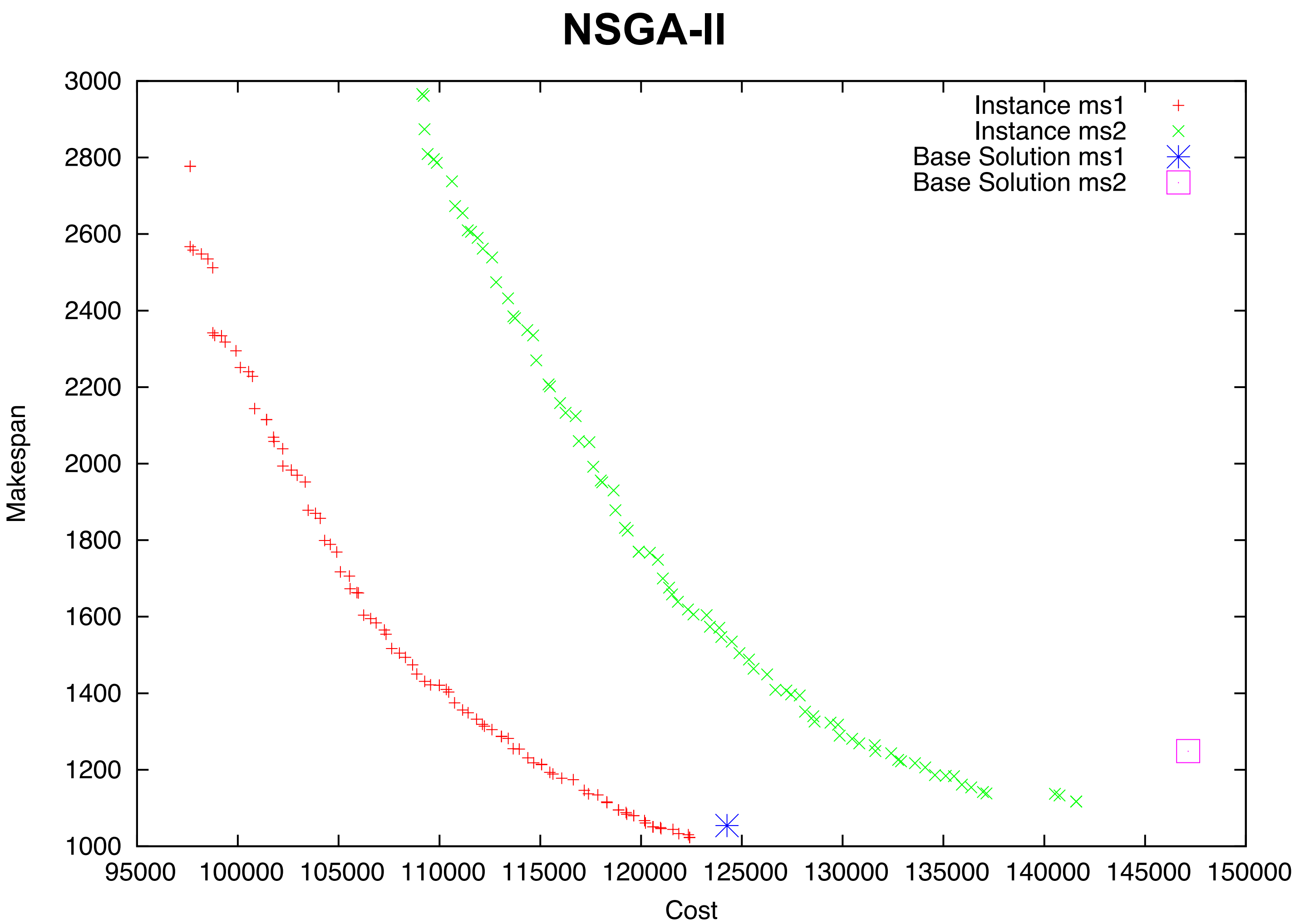
Hypervolume (HV)

- NSGA-II and MOCell are the best algorithms
- NSGA-II is specially good in robust versions of the problem
- MOCell is good in the non-robust version
- PAES is the worst algorithm in the comparison
- Running time between 2.5 and 5 minutes in NR and around 5 hours in OTR and STR

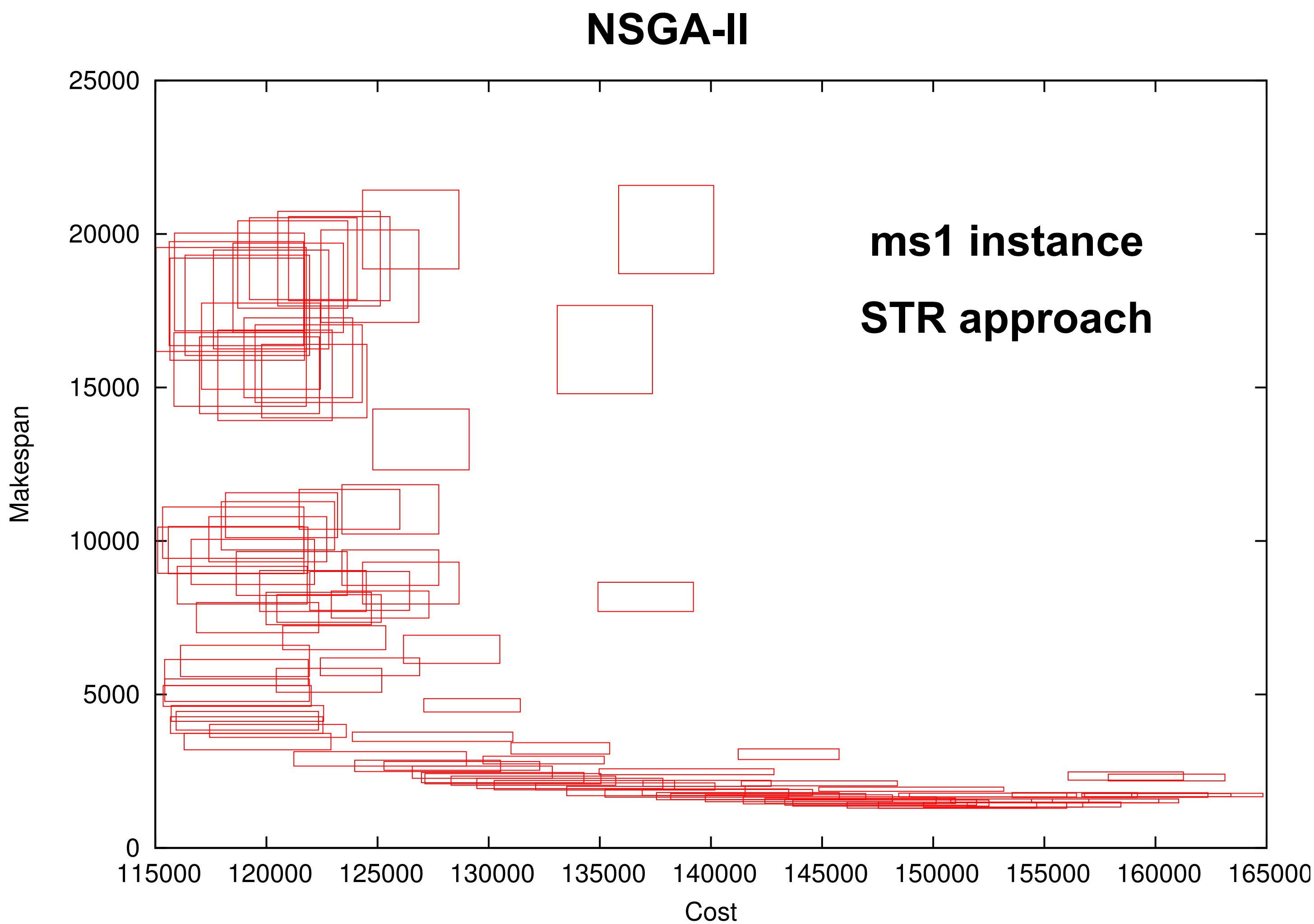
Median and interquartile range

	NSGAII	SPEA2	PAES	MOCell	NSGAII	SPEA2	PAES	MOCell
Rob.	ms1				ms2			
NR	$0.943^*_{0.000}$	$0.943^*_{0.000}$	$0.518^*_{0.065}$	$0.944_{0.000}$	$0.904^*_{\pm 0.000}$	$0.905^*_{\pm 0.001}$	$0.543^*_{\pm 0.031}$	$0.905_{\pm 0.000}$
OTR	$0.829^*_{0.027}$	$0.807^*_{0.030}$	$0.328^*_{0.039}$	$0.816_{0.032}$	$0.738_{\pm 0.025}$	$0.730_{\pm 0.018}$	$0.287^*_{\pm 0.020}$	$0.695^*_{\pm 0.043}$
STR	$0.746_{0.028}$	$0.688^*_{0.063}$	$0.345^*_{0.036}$	$0.742_{0.025}$	$0.764_{\pm 0.025}$	$0.717^*_{\pm 0.030}$	$0.387^*_{\pm 0.032}$	$0.769_{\pm 0.022}$

Results: Comparison with a (Human) Base Solution

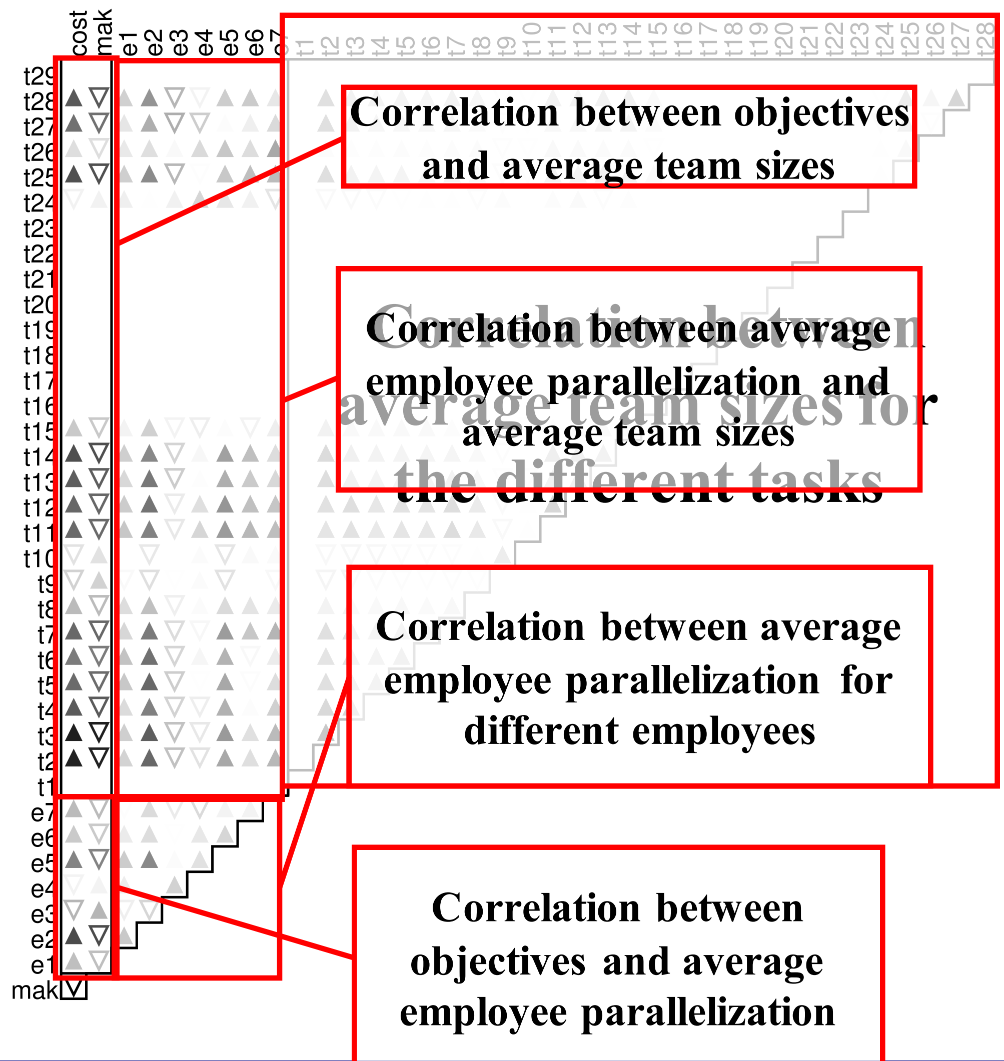


Results: 50%-Attainment Surface



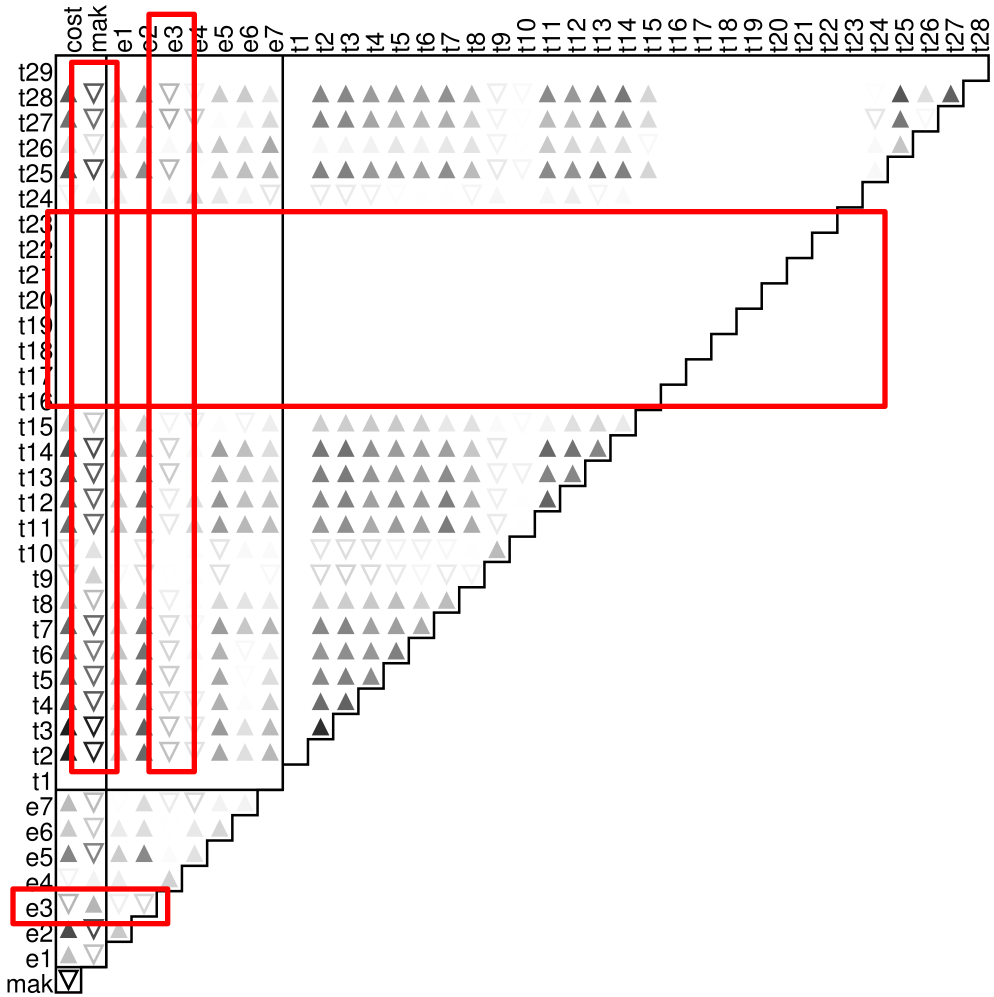
Results: Analysis of the Solution Features

- **Spearman rank correlation coefficients** of the solutions in an approximated Front
  - ▲ : **positive** correlation
  - ▽ : **negative** correlation
  - Gray scale: **absolute** value of correlation
- An example for an approximated Pareto front of **MOCell** using the NR approach in the **ms2** instance



Results: Analysis of the Solution Features

- **Increasing the size of the working teams the makespan is reduced**
- **Employee e_3 is the only one able to perform a task in the critical path**
- **No correlation is observed in tasks for which only one employee can do the work**

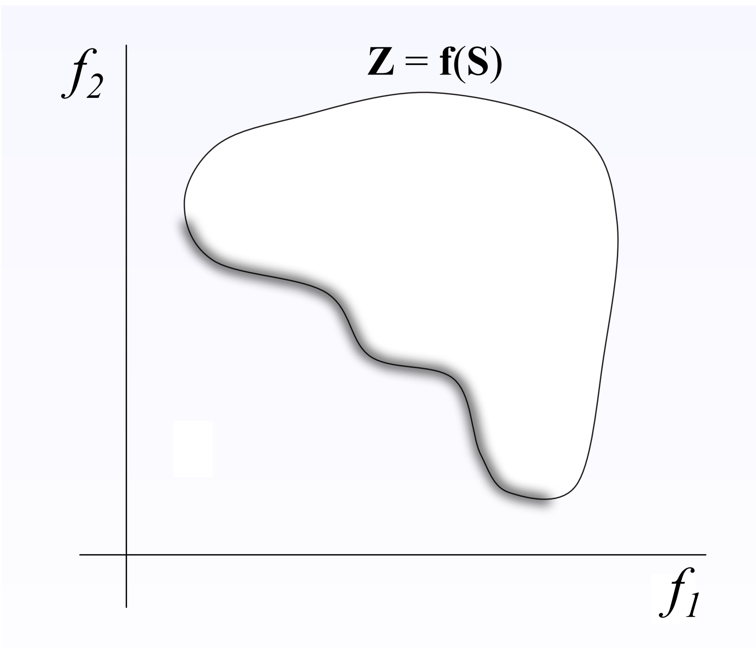


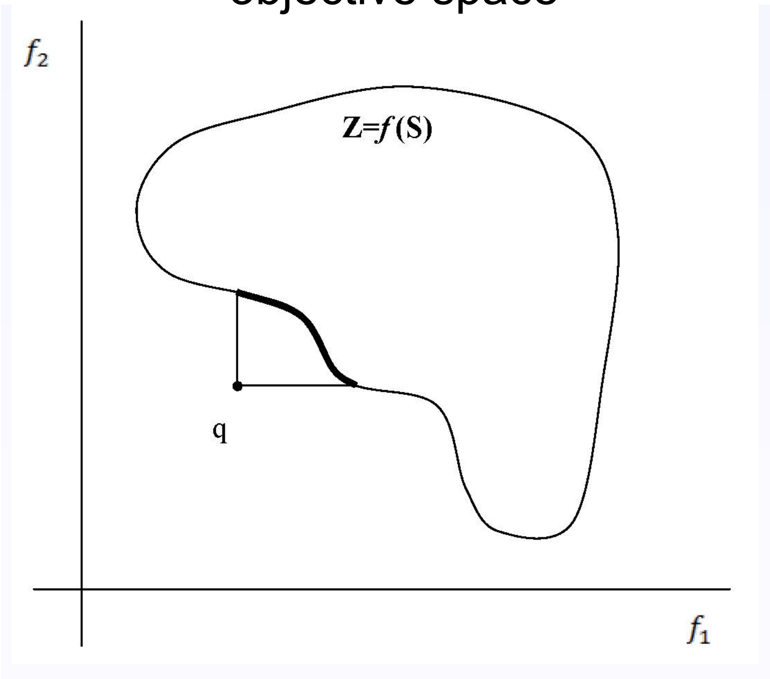
Interactive Preference-Based Resolution

Expressing Preferences in Objective Space

- Sometimes the decision maker is not interested in the whole Pareto front…

… only in a region of the objective space

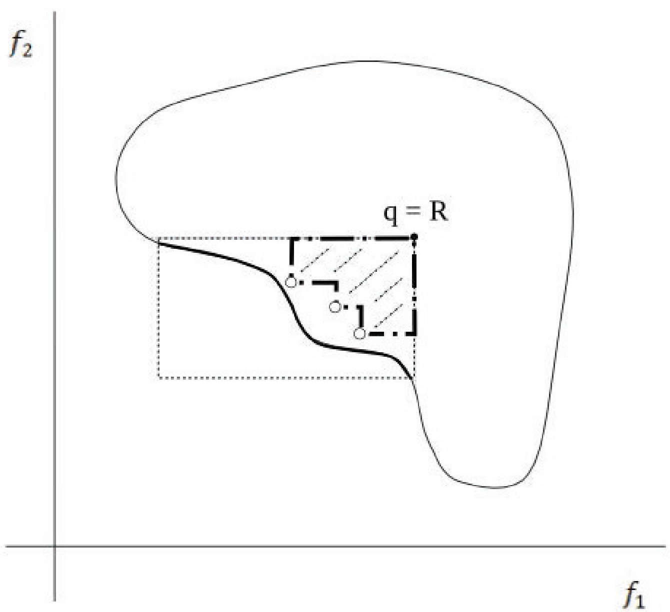




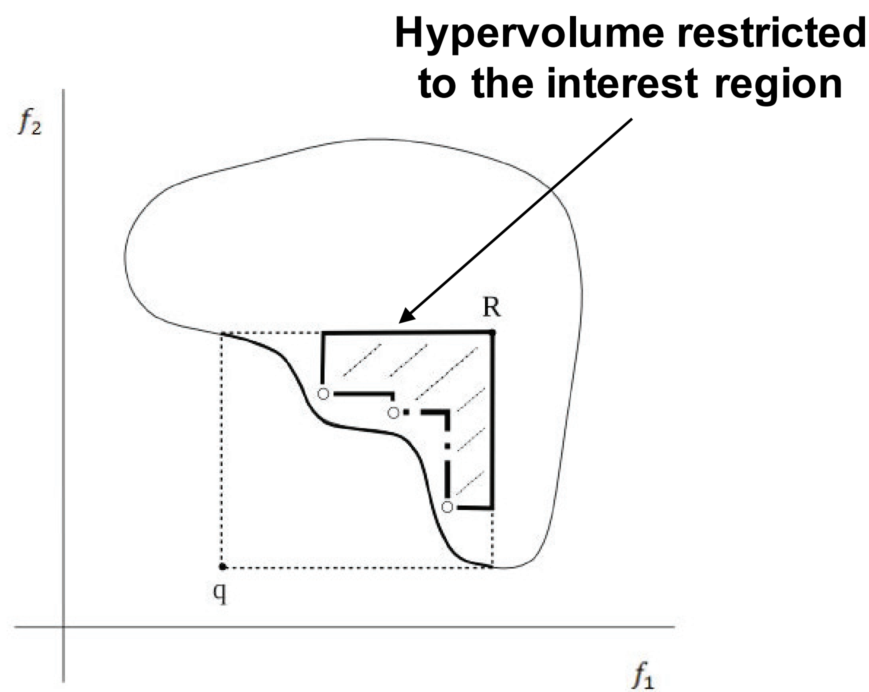
The algorithm can save computational effort if it focuses on the region of interest

Expressing Preferences in Objective Space

- The region of interest can be determined by a single point in the objective space: the reference point



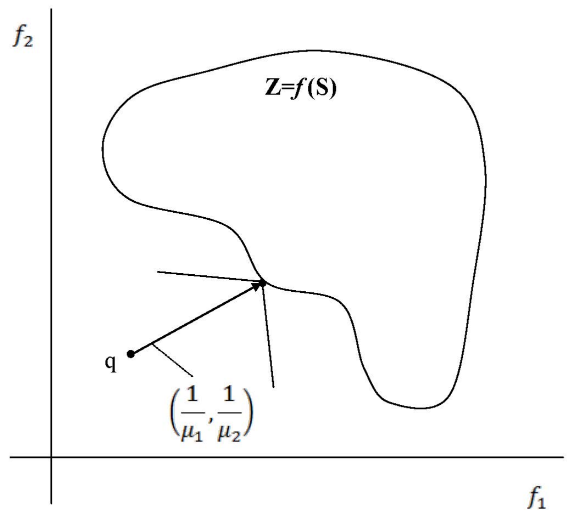
Reachable reference point

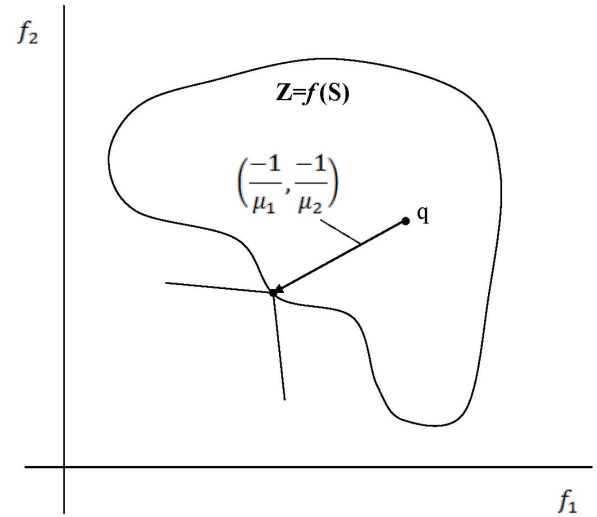


Unreachable reference point

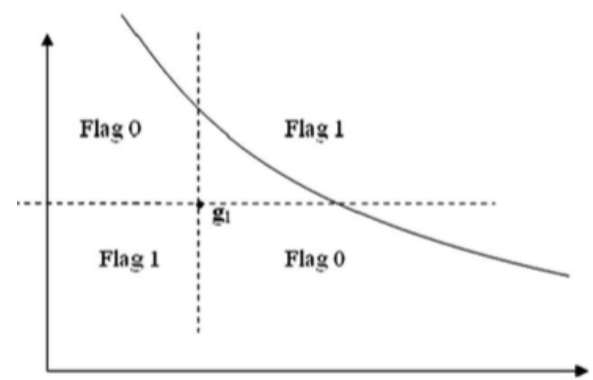
Algorithms

- Some algorithms to solve the problem
  - WASF-GA



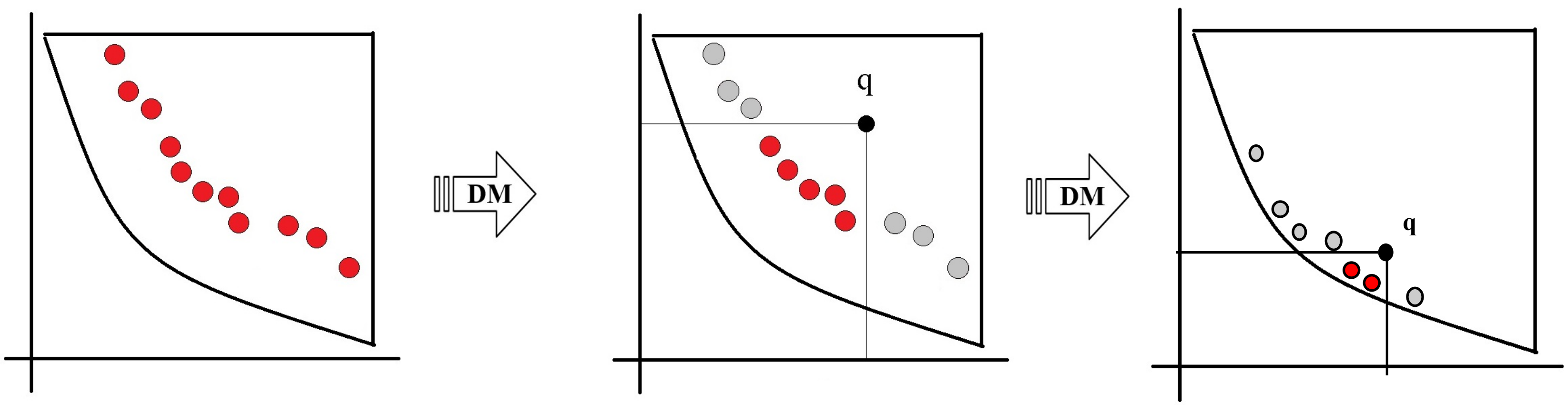


  - g-NSGA-II (based on g-dominance)
  - P-MOGA (similar to WASF-GA)



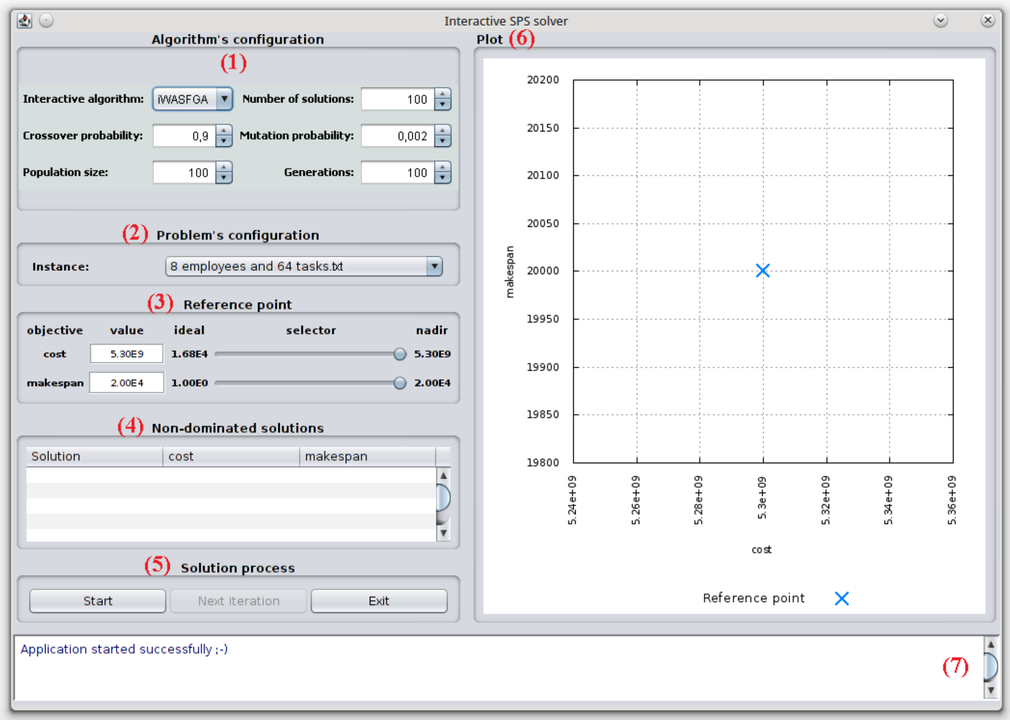
Interaction with Decision Maker

- If the decision maker is available, he can interactively guide the search by defining different reference points



Software Tool

- We developed a tool for interactive preference-based resolution



Concluding Remarks

- Search algorithms are useful to take decisions at the management level
- Some published ideas have been shown in this presentation…
- ...but much more opportunities are waiting for us
  - New algorithmic proposals
  - More realistic models
  - ...
  - … and real data

Thanks for your attention !!!

Resultados

First instances group

Employees	Hit rate	Duration	E^*p_{dur}
5	87	$21{,}88_{0{,}91}$	$109{,}40_{4{,}54}$
10	65	$11{,}27_{0{,}32}$	$112{,}74_{3{,}17}$
15	49	$7{,}73_{0{,}20}$	$115{,}90_{2{,}95}$
20	51	$5{,}88_{0{,}14}$	$117{,}56_{2{,}74}$

- **Duration decreases as number of employee increases**

Resultados

Second group of instances

Tareas	Tasa éxito	Coste	Duración	p_{cost} / p_{dur}
10	73	$980000_{0,00}$	$21,84_{0,87}$	$44944,34_{1720,76}$
20	33	$2600000_{0,00}$	$58,29_{3,76}$	$44748,12_{2265,24}$
30	0	-	-	-

- **La duración disminuye al aumentar el número de empleados**
- **La duración aumenta con el número de tareas**

Resultados

Segundo grupo de instancias

Tareas	Tasa éxito	Coste	Duración	p_{cost} / p_{dur}
10	73	$980000_{0,00}$	$21,84_{0,87}$	$44944,34_{1720,76}$
20	33	$2600000_{0,00}$	$58,29_{3,76}$	$44748,12_{2265,24}$
30	0	-	-	-

- La **duración disminuye** al aumentar el número de empleados
- La **duración aumenta** con el número de tareas

E. Alba & F. Chicano, Software Project Management with GAs, Information Sciences 177, pp. 2380-2401, 2007

Resultados

Tercer grupo de instancias

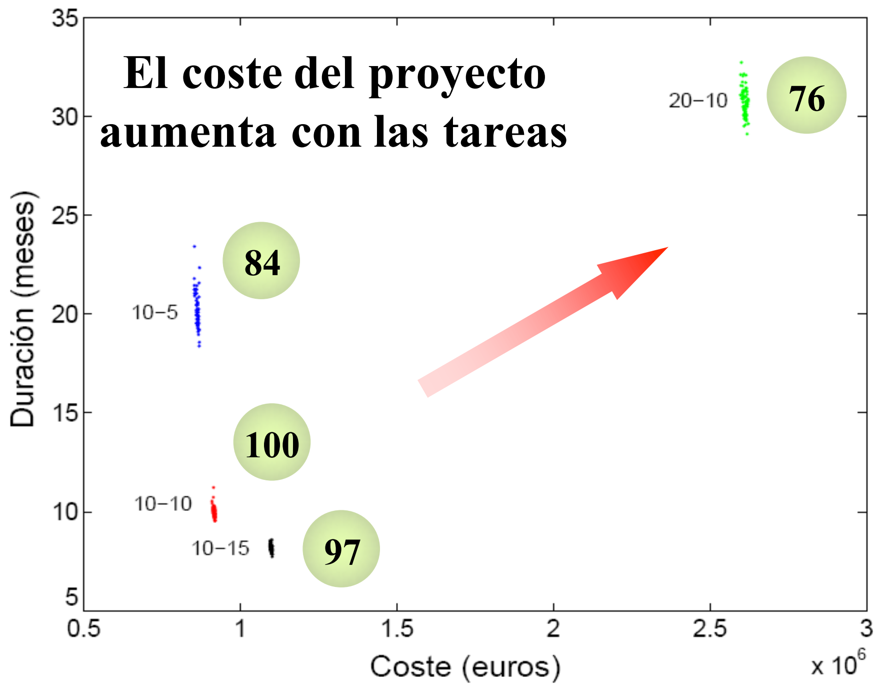
Habilidades	Tasa éxito	Duración	p_{cost} / p_{dur}
2	39	$21{,}71_{0{,}97}$	$45230{,}22_{1957{,}89}$
4	53	$21{,}77_{0{,}75}$	$45068{,}66_{1535{,}53}$
6	77	$21{,}98_{0{,}84}$	$44651{,}29_{1593{,}47}$
8	66	$22{,}00_{0{,}87}$	$44617{,}01_{1717{,}67}$
10	75	$22{,}11_{1{,}15}$	$44426{,}93_{2051{,}03}$

- La **duración disminuye** al aumentar el número de empleados
- La **duración aumenta** con el número de tareas
- **Asignación más eficiente** con plantilla especializada

E. Alba & F. Chicano, Software Project Management with GAs, Information Sciences 177, pp. 2380-2401, 2007

Resultados

Cuarto grupo de instancias



6-7 habilidades por empleado

E. Alba & F. Chicano, Management of Software Projects with GAs, MIC 2005, pp. 13-18

Algorithms: NSGA-II

```
proc Input:(nsga-II)        //Algorithm parameters in 'nsga-II'
P ← Initialize_Population() // P = population
Q ← ∅                              // Q = auxiliary population
while not Termination_Condition() do
    for i ← 1 to (nsga-II.popSize / 2) do
        parents←Selection(P)
        offspring←Recombination(nsga-II.Pc,parents)
        offspring←Mutation(nsga-II.Pm,offspring)
        Evaluate_Fitness(offspring)
        Insert(offspring,Q)
    end for
    R ← P ∪ Q
    Ranking_And_Crowding(nsga-II, R)
    P ←Select_Best_Individuals(nsga-II, R)
end while
end_proc
```

Algorithms: PAES

```
proc Input:(paes)        //Algorithm parameters in 'paes'
archive ← ∅
currentSolution ← Create_Solution(paes) // Creates an initial solution
while not Termination_Condition() do
    mutatedSolution←Mutation(currentSolution)
    Evaluate_Fitness(mutatedSolution)
    if IsDominated(currentSolution, mutatedSolution) then
        currentSolution ← mutatedSolution
    else
        if Solutions_Are_Nondominated(currentSolution, mutatedSolution) then
            Insert(archive, mutatedSolution)
            currentSolution ← Select(paes, archive)
        end if
    end if
end while
end_proc
```