Julia Tutorial (3)
MultiObjective Metaheuristic Implementation
Part II: non-exact methods

https://github.com/jMetal/MetaJul/resources

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MultiObjective Metaheuristics

- When a multi-objective problem cannot be solved with exact tecniques the alternative is to use non-exact methods, such as metaheuristics

Metaheuristics in Combinatorial Optimization: Overview and Conceptual Comparison

CHRISTIAN BLUM

Université Libre de Bruxelles

AND

ANDREA ROLI

Università degli Studi di Bologna

ACM Computing Surveys, Vol. 35, No. 3, September 2003.

"Metaheuristics are high level strategies for exploring search spaces by using different methods.

MultiObjective MOEAs

- The question is how to implement a multi-objective metaheuristic
  - Multi-Objective Evolutionary Algorithms (MOEAs)
- The adopted scheme will influence in
  - Code easy to understand
  - Efficiency
  - Reusability and extensibility

MultiObjective MOEAs

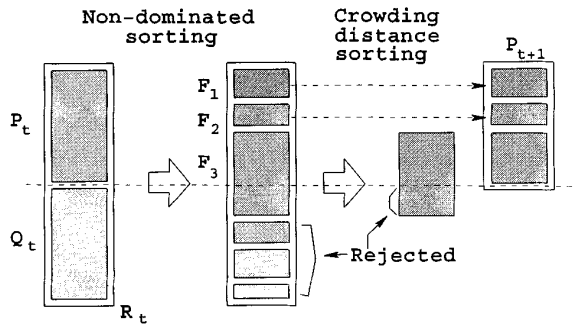
- Our focus:
  - Implementation of NSGA-II in Julia
  - Solving the example problem

$$
\begin{array}{lrcrcrl}
\max z_1 & = & x_1 & + & x_2 & & \\
\min z_2 & = & x_1 & + & 3x_2 & & \\
s.t. & & 2x_1 & + & 3x_2 & \leqslant & 30 \\
 & & 3x_1 & + & 2x_2 & \leqslant & 30 \\
 & & x_1 & - & x_2 & \leqslant & 5.5 \\
 & & x_1 & , & x_2 & \in & \mathbb{N}
\end{array}
$$

MultiObjective MOEAs

A Fast and Elitist Multiobjective Genetic Algorithm: NSGA-II

Kalyanmoy Deb, *Associate Member, IEEE*, Amrit Pratap, Sameer Agarwal, and T. Meyarivan



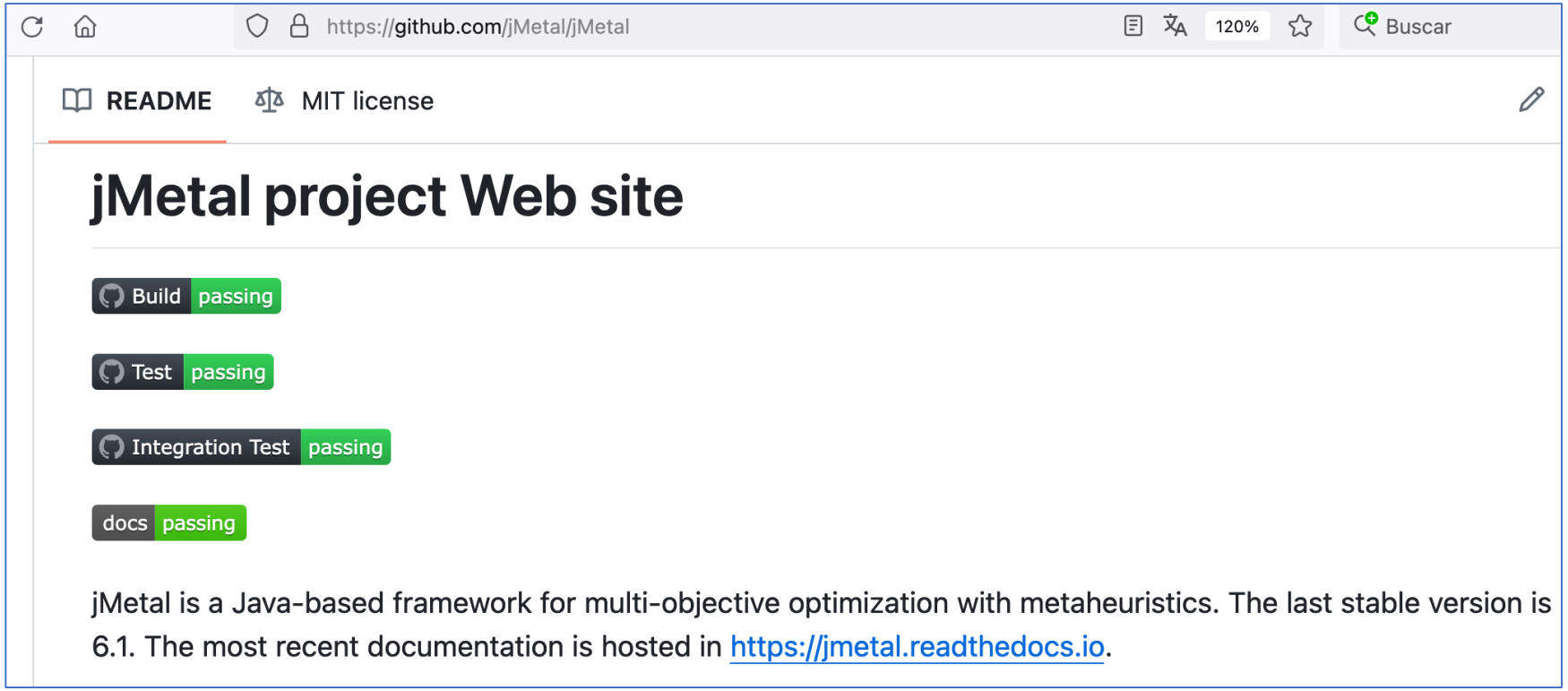
$R_t = P_t \cup Q_t$ — combine parent and offspring population
$\mathcal{F} = \texttt{fast-non-dominated-sort}(R_t)$ — $\mathcal{F} = (\mathcal{F}_1, \mathcal{F}_2, \ldots)$, all nondominated fronts of R_t
$P_{t+1} = \emptyset$ and $i = 1$
until $|P_{t+1}| + |\mathcal{F}_i| \leq N$ — until the parent population is filled
  $\texttt{crowding-distance-assignment}(\mathcal{F}_i)$ — calculate crowding-distance in $\mathcal{F}_i$
  $P_{t+1} = P_{t+1} \cup \mathcal{F}_i$ — include ith nondominated front in the parent pop
  $i = i + 1$ — check the next front for inclusion
$\text{Sort}(\mathcal{F}_i, \prec_n)$ — sort in descending order using $\prec_n$
$P_{t+1} = P_{t+1} \cup \mathcal{F}_i[1 : (N - |P_{t+1}|)]$ — choose the first $(N - |P_{t+1}|)$ elements of $\mathcal{F}_i$
$Q_{t+1} = \texttt{make-new-pop}(P_{t+1})$ — use selection, crossover and mutation to create a new population Q_{t+1}
$t = t + 1$ — increment the generation counter

?

Algorithm 1 Pseudo-code of an evolutionary algorithm

1: $P(0) \leftarrow$ GenerateInitialSolutions()
2: $t \leftarrow 0$
3: Evaluate($P(0)$)
4: **while not** StoppingCriterion() **do**
5: $M(t) \leftarrow$ Select($P(t)$)
6: $Q(t) \leftarrow$ Variate($M(t)$)
7: Evaluate($Q(t)$)
8: $P(t+1) \leftarrow$ Update($P(t)$, $Q(t)$)
9: $t \leftarrow t + 1$
10: **end while**

Implementing NSGA-II in jMetal



https://github.com/jMetal

Implementing NSGA-II in jMetal

- Three alternatives
  - Monolitic
    - jMetal 4.3 (2012): https://github.com/jMetal/jMetal/blob/v4.3/jmetal/metaheuristics/nsgaII/NSGAII.java
  - Object-oriented
    - jMetal 5.0 (2015):
      - https://github.com/jMetal/jMetal/blob/main/jmetal-core/src/main/java/org/uma/jmetal/algorithm/impl/AbstractEvolutionaryAlgorithm.java
      - https://github.com/jMetal/jMetal/blob/main/jmetal-algorithm/src/main/java/org/uma/jmetal/algorithm/multiobjective/nsgaii/NSGAII.java
  - Component-based
    - jMetal 6.0 (2022)
      - https://github.com/jMetal/jMetal/blob/main/jmetal-component/src/main/java/org/uma/jmetal/component/algorithm/EvolutionaryAlgorithm.java
      - https://github.com/jMetal/jMetal/blob/main/jmetal-component/src/main/java/org/uma/jmetal/component/algorithm/multiobjective/NSGAIIBuilder.java

Implementing NSGA-II in jMetal

Algorithm 1 Pseudo-code of an evolutionary algorithm

```
1: P(0) ← GenerateInitialSolutions()
2: t ← 0
3: Evaluate(P(0))
4: while not StoppingCriterion() do
5:    M(t) ← Select(P(t))
6:    Q(t) ← Variate(M(t))
7:    Evaluate(Q(t))
8:    P(t + 1) ← Update(P(t), Q(t))
9:    t ← t + 1
10: end while
```

```java
public class EvolutionaryAlgorithm<S>

  public void run() {
    population = createInitialPopulation.create();
    population = evaluation.evaluate(population);
    initProgress();
    while (!termination.isMet(attributes)) {
        List<S> matingPopulation = selection.select(population);
        List<S> offspringPopulation = variation.variate(population, matingPopulation);
        offspringPopulation = evaluation.evaluate(offspringPopulation);

        population = replacement.replace(population, offspringPopulation);
        updateProgress();
    }
}
```

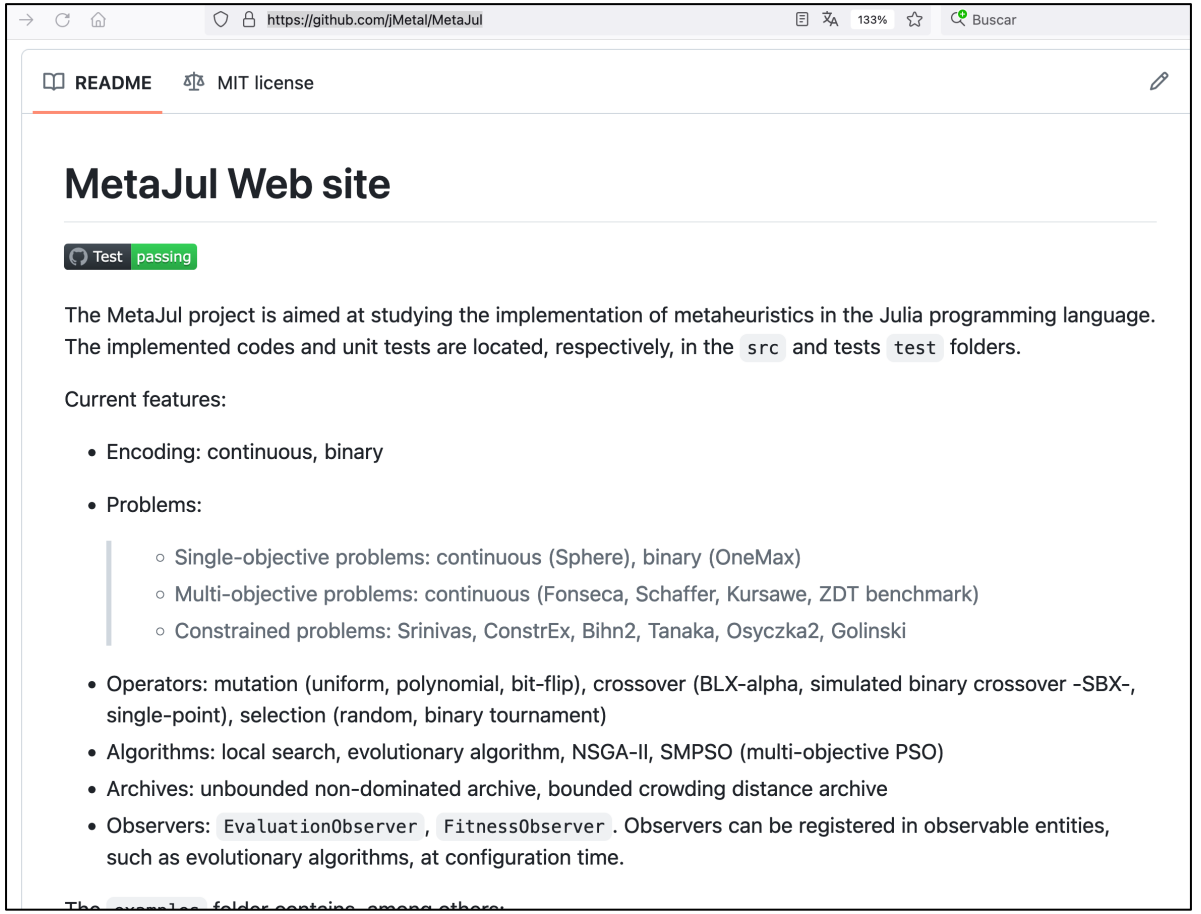
Component-based architecture

Component	Implementations
Solutions creation	Latin hypercube sampling
	Random
	Scatter Search
Evaluation	Sequential
	Multithreaded
	Sequential with external archive
Termination	Computing time
	Evaluations
	Keyboard
	Quality indicator
Selection	N-ary tournament
	Random
	Differential evolution
	Neighborhood
	Population and neighborhood
Variation	Crossover and mutation
	Differential evolution
Replacement	(μ, λ)
	$(\mu + \lambda)$
	Ranking and density estimator
	Pairwise
	MOEA/D replacement strategy
	SMS-EMOA replacement strategy

Component catalog

Implementing NSGA-II in Julia

- MetaJul project



https://github.com/jMetal/MetaJul/

Implementing NSGA-II in Julia

jMetal

```
public class EvolutionaryAlgorithm<S>

  public void run() {
    population = createInitialPopulation.create();
    population = evaluation.evaluate(population);
    initProgress();
    while (!termination.isMet(attributes)) {
        List<S> matingPopulation = selection.select(population);
        List<S> offspringPopulation = variation.variate(population, matingPopulation);
        offspringPopulation = evaluation.evaluate(offspringPopulation);

        population = replacement.replace(population, offspringPopulation);
        updateProgress();
    }
}
```

Algorithm 1 Pseudo-code of an evolutionary algorithm

1: $P(0) \leftarrow$ GenerateInitialSolutions()
2: $t \leftarrow 0$
3: Evaluate($P(0)$)
4: **while not** StoppingCriterion() **do**
5: $M(t) \leftarrow$ Select($P(t)$)
6: $Q(t) \leftarrow$ Variate($M(t)$)
7: Evaluate($Q(t)$)
8: $P(t+1) \leftarrow$ Update($P(t), Q(t)$)
9: $t \leftarrow t+1$
10: **end while**

MetaJul

```
mutable struct EvolutionaryAlgorithm <: Algorithm
    name::String

    foundSolutions::Vector

    solutionsCreation::SolutionsCreation
    evaluation::Evaluation
    termination::Termination
    selection::Selection
    variation::Variation
    replacement::Replacement
end



function evolutionaryAlgorithm(ea::EvolutionaryAlgorithm)
    population = create(ea.solutionsCreation)
    population = evaluate(ea.evaluation, population)

    evaluations = length(population)

    while !isMet(ea.termination, ea.status)
        matingPool = select(ea.selection, population)
        offspringPopulation = variate(ea.variation, population, matingPool)
        offspringPopulation = evaluate(ea.evaluation, offspringPopulation)
        population = replace_(ea.replacement, population, offspringPopulation)

        evaluations += length(offspringPopulation)¡
    end
    foundSolutions = population
    return foundSolutions
end
```

Implementing the problem in MetaJul

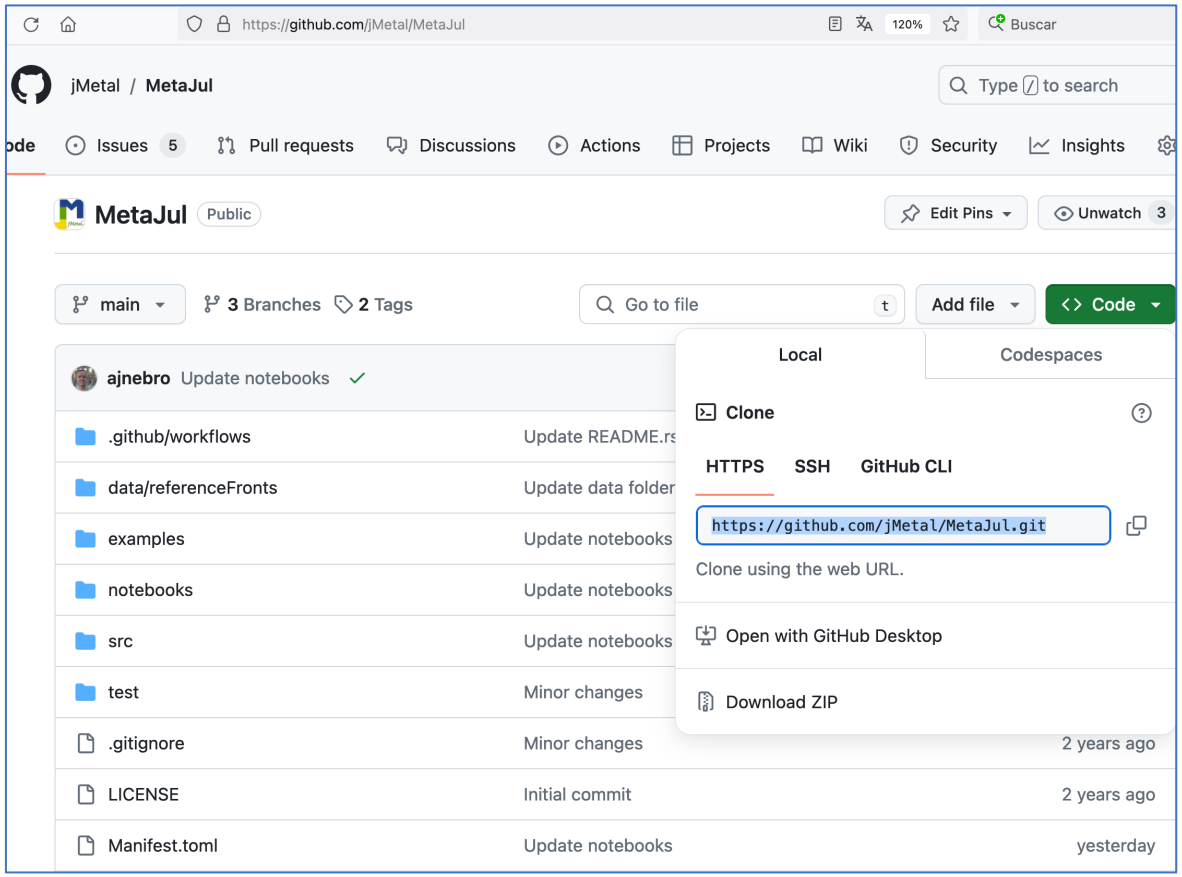
$$
\begin{array}{lcrcrcl}
\max z_1 & = & x_1 & + & x_2 & & \\
\min z_2 & = & x_1 & + & 3x_2 & & \\
s.t. & & 2x_1 & + & 3x_2 & \leqslant & 30 \\
 & & 3x_1 & + & 2x_2 & \leqslant & 30 \\
 & & x_1 & - & x_2 & \leqslant & 5.5 \\
 & & x_1 & , & x_2 & \in & \mathbb{N}
\end{array}
$$

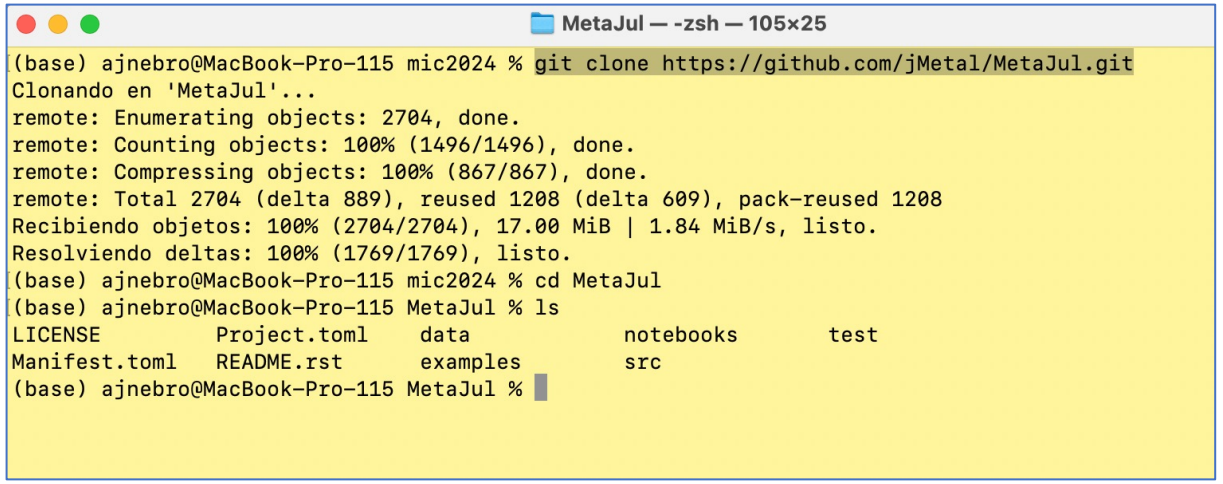
```
problem = ContinuousProblem{Int64}("integerProblem")

addVariable(problem, Bounds{Int64}(0, 20))
addVariable(problem, Bounds{Int64}(0, 20))

f1 = x -> -1.0 * (x[1] + x[2])
f2 = x -> x[1] + 3 * x[2]

addObjective(problem, f1)
addObjective(problem, f2)

c1 = x -> -2 * x[1] - 3 * x[2] + 30.0
c2 = x -> -3 * x[1] - 2 * x[2] + 30.0
c3 = x -> -x[1] + x[2] + 5.5

addConstraint(problem, c1)
addConstraint(problem, c2)
addConstraint(problem, c3)
```

```
julia> model = Model( )
julia> @variable(model, x1⩾0, Int)
julia> @variable(model, x2⩾0, Int)
julia> @expression(model, fct1, x1 + x2)                # to maximize
julia> @expression(model, fct2, x1 + 3 * x2)            # to minimize
julia> @objective(model, Max, [fct1, (-1) * fct2]))
julia> @constraint(model, 2*x1 + 3*x2 ⩽ 30))
julia> @constraint(model, 3*x1 + 2*x2 ⩽ 30))
julia> @constraint(model, x1 - x2 ⩽ 5.5))
```

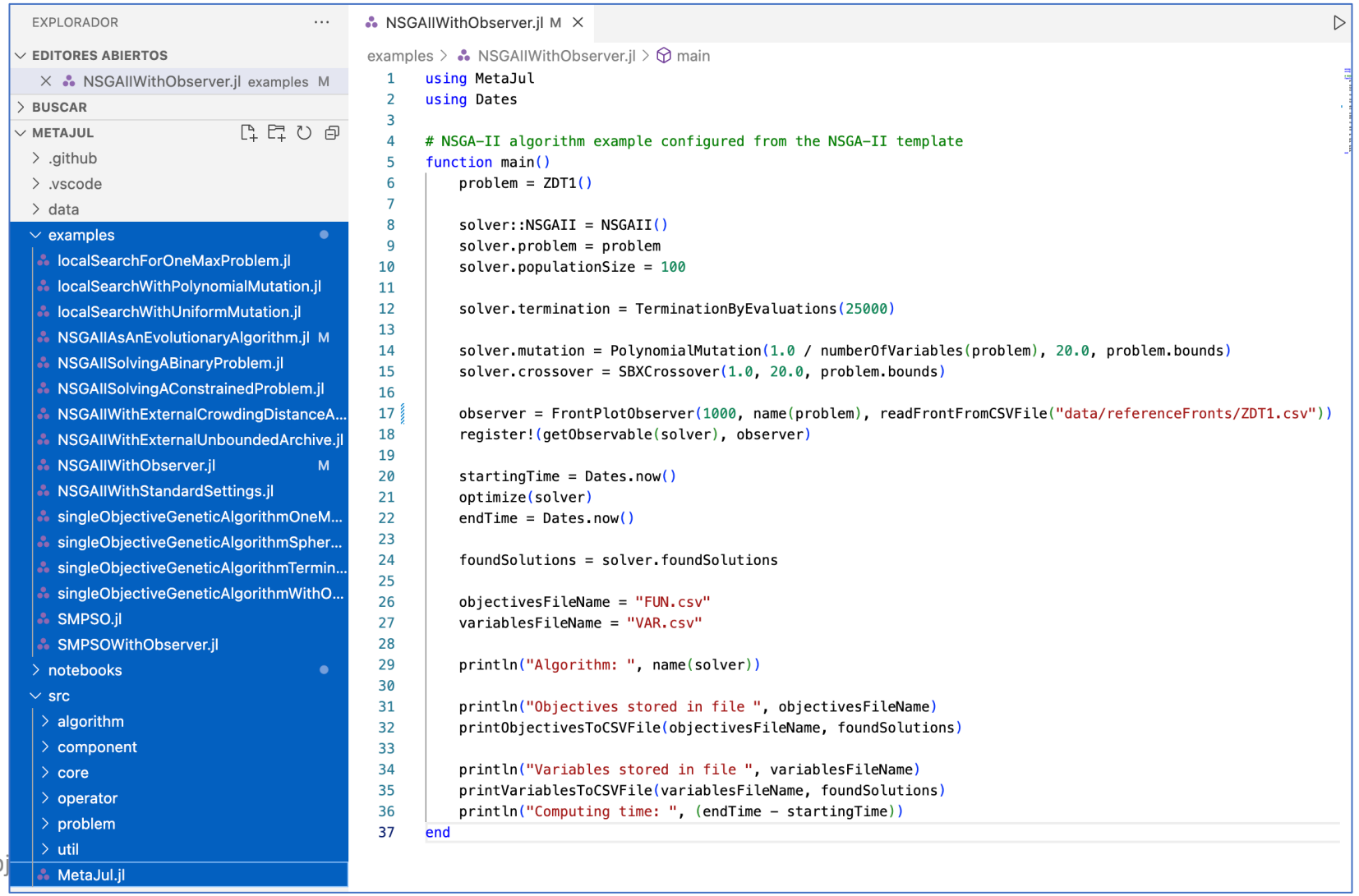
Getting starting with MetaJul

- Download the project from https://github.com/jMetal/MetaJul



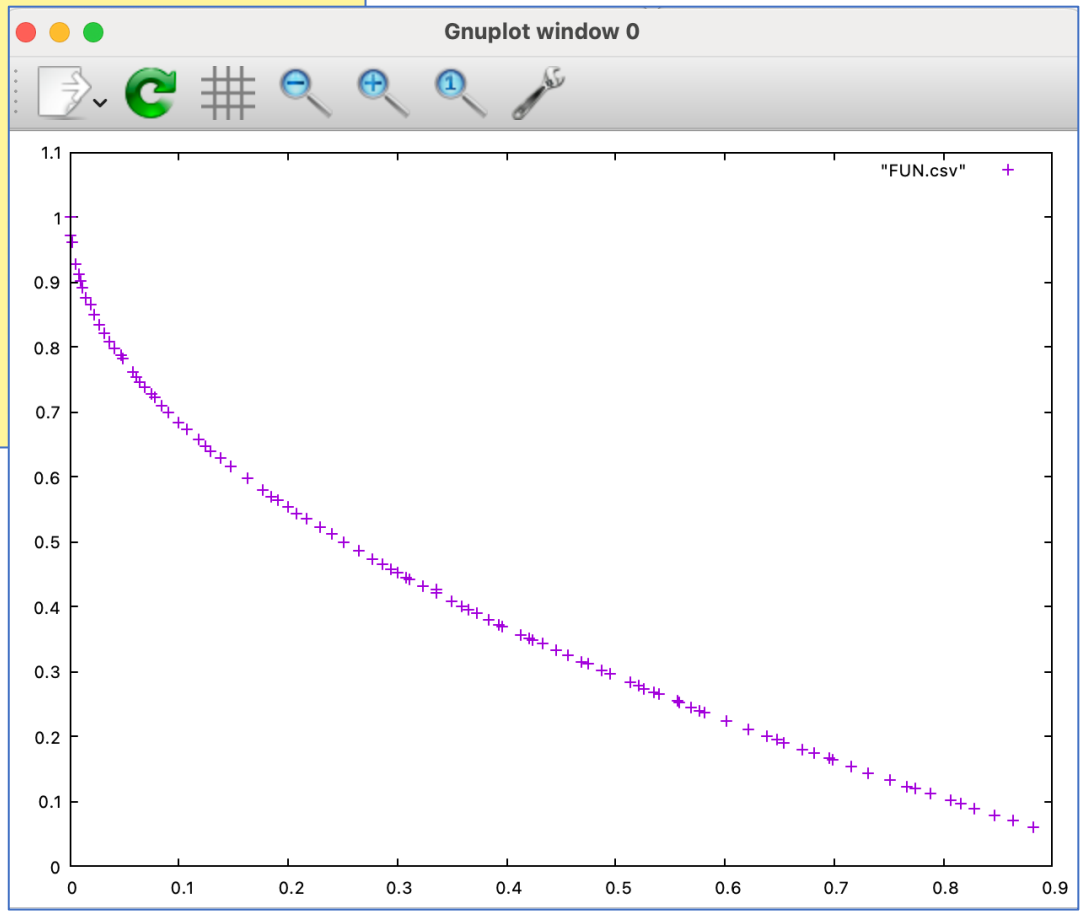


Project structure



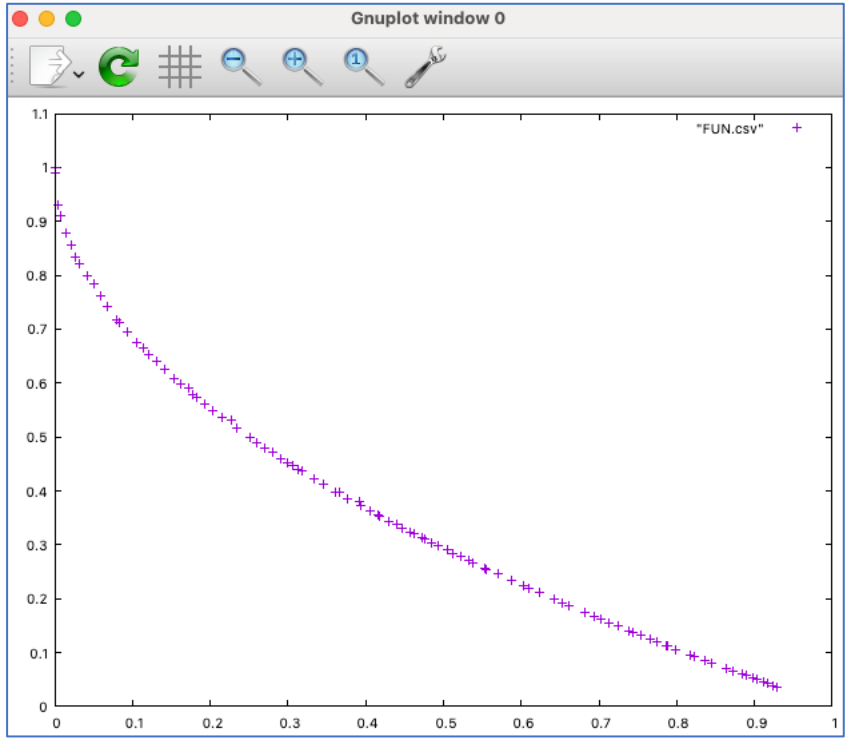
Running NSGA-II from the command line

```
(base) ajnebro@MacBook-Pro-115 MetaJul % julia --project=. -L "examples/NSGAIIAsAnEvolutionaryAlgorithm.jl" -e "main()"
Algorithm: NSGA-II
Computing time: 1701 milliseconds
Objectives stored in file FUN.csv
Variables stored in file VAR.csv
(base) ajnebro@MacBook-Pro-115 MetaJul % gnuplot

        G N U P L O T
        Version 6.0 patchlevel 0    last modified 2023-12-09

        Copyright (C) 1986-1993, 1998, 2004, 2007-2023
        Thomas Williams, Colin Kelley and many others

        gnuplot home:     http://www.gnuplot.info
        faq, bugs, etc:   type "help FAQ"
        immediate help:   type "help"  (plot window: hit 'h')

        Terminal type is now qt
gnuplot> set datafile separator ','
gnuplot> plot "FUN.csv"
```

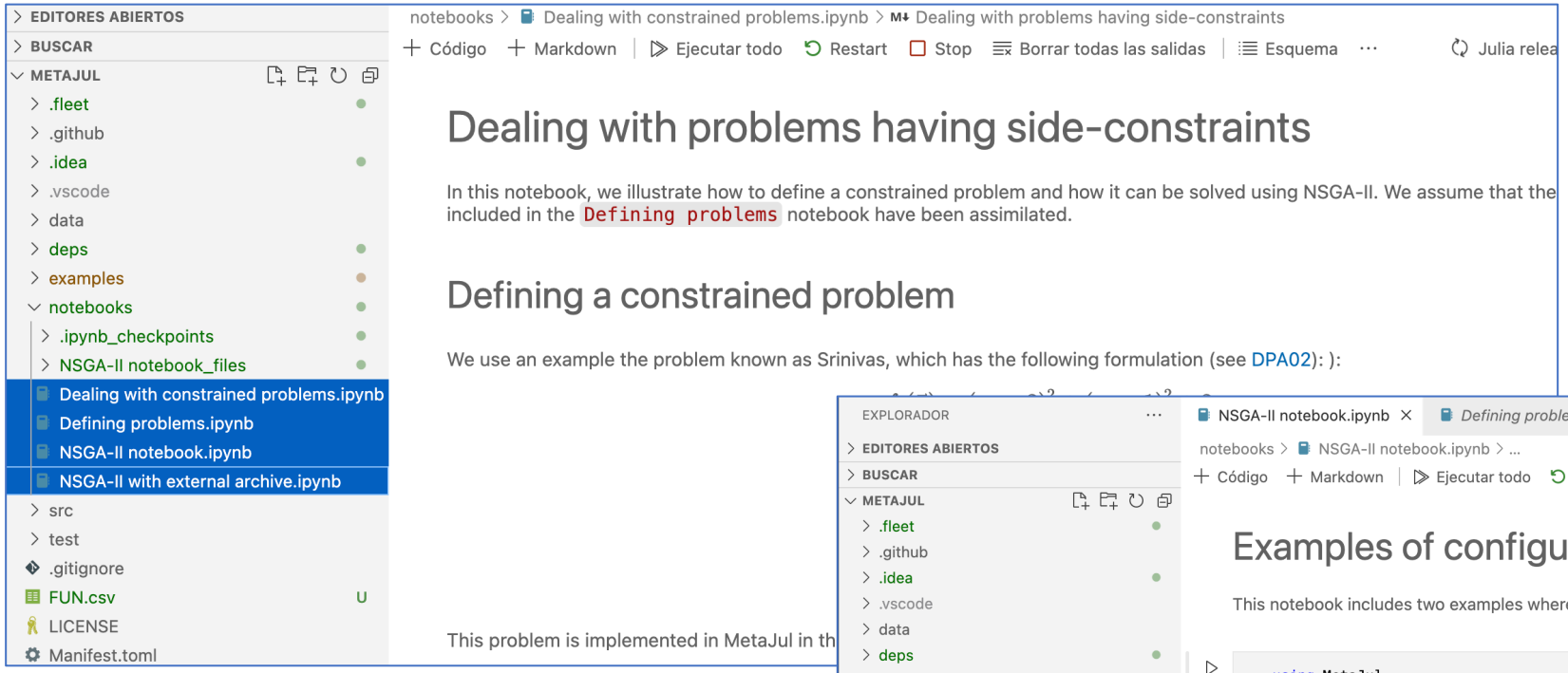


Running NSGA-II from the REPL

```
(base) ajnebro@MacBook-Pro-115 metajul % julia --project=.
               _
   _       _ _(_)_     |  Documentation: https://docs.julialang.org
  (_)     | (_) (_)    |
   _ _   _| |_  __ _   |  Type "?" for help, "]?" for Pkg help.
  | | | | | | |/ _` |  |
  | | |_| | | | (_| |  |  Version 1.10.3 (2024-04-30)
 _/ |\__'_|_|_|\__'_|  |  Official https://julialang.org/ release
|__/                   |

julia> include("examples/NSGAIIAsAnEvolutionaryAlgorithm.jl")
main (generic function with 1 method)

julia> main()
Algorithm: NSGA-II
Computing time: 1370 milliseconds
Objectives stored in file FUN.csv
Variables stored in file VAR.csv

julia> main()
Algorithm: NSGA-II
Computing time: 821 milliseconds
Objectives stored in file FUN.csv
Variables stored in file VAR.csv

julia>
(base) ajnebro@MacBook-Pro-115 metajul % gnuplot

        G N U P L O T
        Version 6.0 patchlevel 0    last modified 2023-12-09

        Copyright (C) 1986-1993, 1998, 2004, 2007-2023
        Thomas Williams, Colin Kelley and many others

        gnuplot home:     http://www.gnuplot.info
        faq, bugs, etc:   type "help FAQ"
        immediate help:   type "help"  (plot window: hit 'h')

        Terminal type is now qt
gnuplot> set datafile separator ','
gnuplot> plot "FUN.csv"
qt.qpa.fonts: Populating font family aliases took 57 ms. Replace uses of missing font family
_"Sans" with one that exists to avoid this cost.
gnuplot>
```



Notebooks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data
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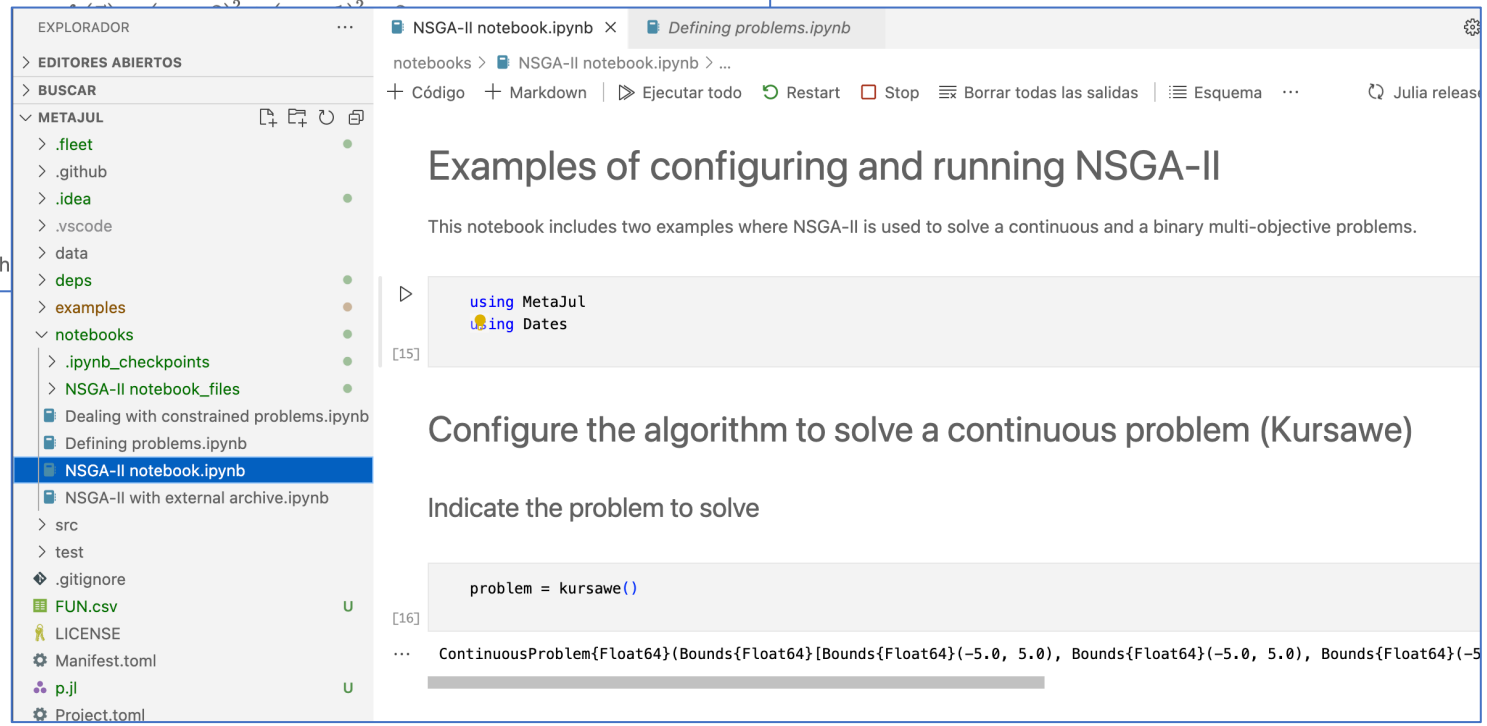
examples
notebooks
.ipynb_checkpoints
NSGA-II notebook_files
Dealing with constrained problems.ipynb
Defining problems.ipynb
NSGA-II notebook.ipynb
NSGA-II with external archive.ipynb
src
test
.gitignore
FUN.csv
LICENSE
Manifest.toml
notebooks > Dealing with constrained problems.ipynb > Dealing with problems having side-constraints
Código
Markdown
Ejecutar todo
Restart
Stop
Borrar todas las salidas
Esquema
Julia relea
Dealing with problems having side-constraints
In this notebook, we illustrate how to define a constrained problem and how it can be solved using NSGA-II. We assume that the
included in the Defining problems notebook have been assimilated.
Defining a constrained problem
We use an example the problem known as Srinivas, which has the following formulation (see DPA02):):
This problem is implemented in MetaJul in th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notebooks > NSGA-II notebook.ipynb > ...
Código
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Restart
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Borrar todas las salidas
Esquema
Julia releas
Examples of configuring and running NSGA-II
This notebook includes two examples where NSGA-II is used to solve a continuous and a binary multi-objective problems.
using MetaJul
using Dates
[15]
Configure the algorithm to solve a continuous problem (Kursawe)
Indicate the problem to solve
problem = kursawe()
[16]
ContinuousProblem{Float64}(Bounds{Float64}[Bounds{Float64}(-5.0, 5.0), Bounds{Float64}(-5.0, 5.0), Bounds{Float64}(-5

Thanks for your attention