HeuristicLab

A Paradigm-Independent and Extensible Environment for Heuristic Optimization

Programming HeuristicLab

Algorithms and Problems

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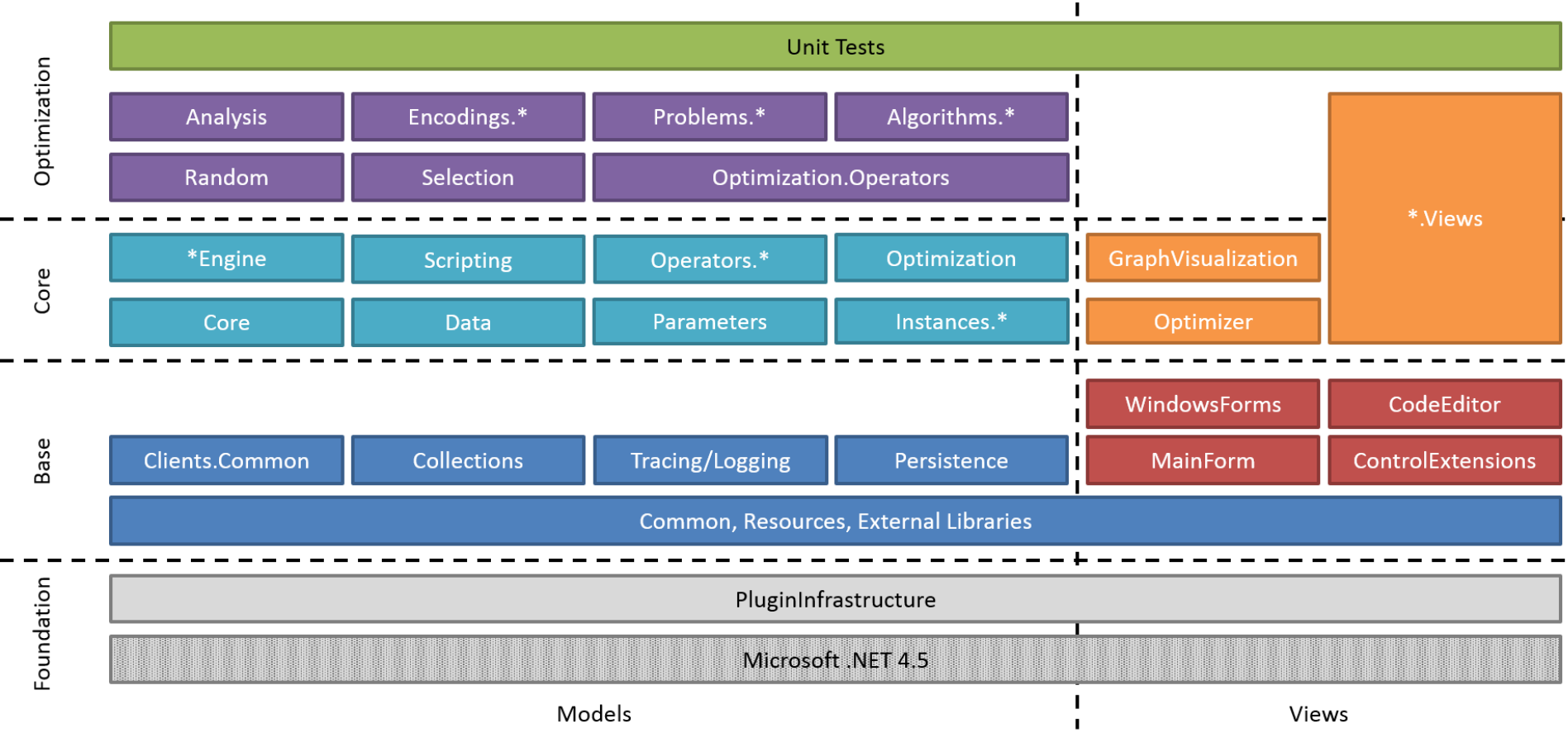
Overview

HeuristicLab

- HL Algorithm Model
- Parameters, Operators and Scopes
- Algorithms
- Problems

Where are we?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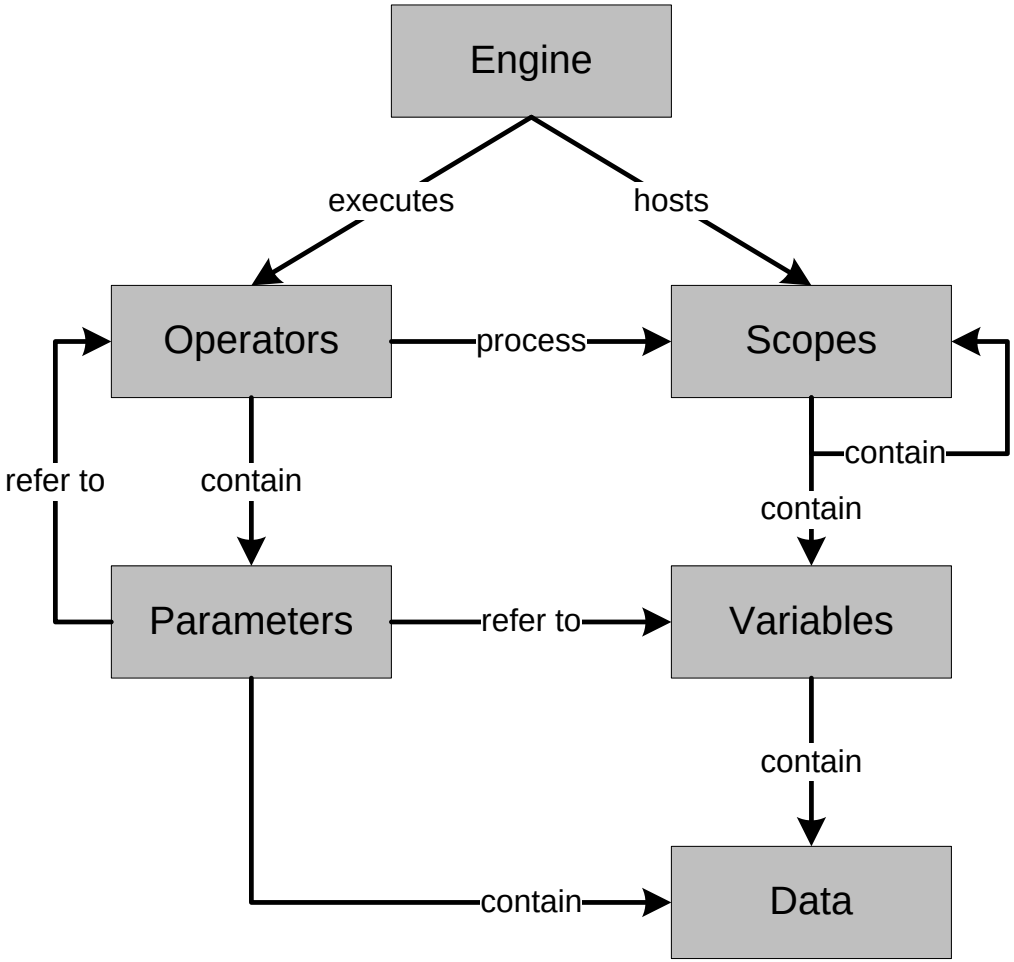
HL Algorithm Model

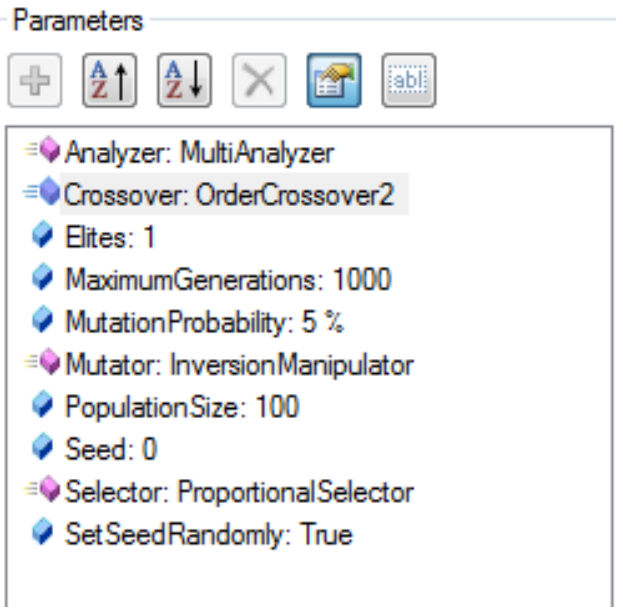
- Typically, HL algorithms are constructed by chaining together operators
- An engine executes these operators
  - Enables pausing and debugging
  - Available engines:
    - Sequential engine
    - Parallel engine
    - Debug engine
    - (Hive engine)

HL Algorithm Model



Parameters

- Used to configure algorithms, problems and operators
- Used for accessing variables in the scope
- E.g. population size, analyzers, crossover operator
- Operators
  - Look up these parameters from the algorithm, problem or scope
  - Use them to store values (in the scope tree)



Parameters

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- ValueParameter:
  - Stores a value (Item) that can be looked up. E.g. mutation rate, crossover operator,…
- LookupParameter:
  - Looks up parameters/items (variables) from the scope/parent scopes.
- ConstrainedValueParameter:
  - Contains a list of selectable values.
- ScopeTreeLookupParameter:
  - Goes down the scope tree and looks up variables.
- ScopeParameter:
  - Returns the current scope.
- ValueLookupParameter, OptionalConstrainedValueParameter, OperatorParameter, FixedValueParameter, OptionalValueParameter,…

Parameters

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- Everything that is a ParameterizedNamedItem has a Parameters collection
- Normally used in the following way:
  - Add parameter to Parameters collection
  - Implement getter for convenience
  - Use parameter
  - Lookup parameter

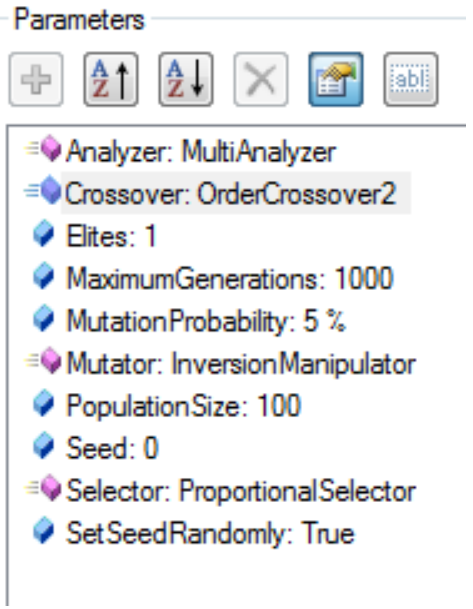
Add parameter to Parameters collection

- The Crossover parameter enables the user to select different crossover operators:

```
Parameters.Add(new ConstrainedValueParameter<ICrossover>("Crossover",
"The operator used to cross solutions."));
```

- The PopulationSize is a freely configurable integer value:

```
Parameters.Add(new ValueParameter<IntValue>("PopulationSize",
"The size of the population of solutions.", new IntValue(100)));
```



Implement getter for convenience

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- Getter for crossover parameter:

```
public IConstrainedValueParameter<ICrossover> CrossoverParameter {
          get { return (IConstrainedValueParameter<ICrossover>)Parameters["Crossover"]; }
}
```

- Getter for PopulationSize parameter:

```
private ValueParameter<IntValue> PopulationSizeParameter {
          get { return (ValueParameter<IntValue>)Parameters["PopulationSize"]; }
}
```

Use parameter

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- Use crossover parameter:

```
ICrossover defaultCrossover = Problem.Operators.OfType<ICrossover>().FirstOrDefault();
foreach (ICrossover crossover in Problem.Operators.OfType<ICrossover>().OrderBy(x => x.Name))
          CrossoverParameter.ValidValues.Add(crossover);
CrossoverParameter.Value = defaultCrossover;
```

- Use PopulationSize parameter:

```
PopulationSizeParameter.Value.Value = 42;
```

Lookup Parameter

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- Defining lookup parameter for crossover:

```
Parameters.Add(new ValueLookupParameter<IOperator>("Crossover",
"The operator used to cross solutions."));


public ValueLookupParameter<IntValue> PopulationSizeParameter {
          get { return (ValueLookupParameter<IntValue>)Parameters["PopulationSize"]; }
}
```

- Defining lookup parameter for population size:

```
Parameters.Add(new ValueLookupParameter<IntValue>("PopulationSize",
"The size of the population."));


public ValueLookupParameter<IOperator> CrossoverParameter {
          get { return (ValueLookupParameter<IOperator>)Parameters["Crossover"]; }
}
```

Use Lookup Parameter

- Set crossover parameter:

```
CrossoverParameter.Value =
ga.CrossoverParameter.ValidValues.Single(x => x.GetType() ==  typeof(OrderCrossover));
```

- Set PopulationSize parameter:

```
PopulationSizeParameter.Value.Value = 42;
```

Use Lookup Parameter

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- In the genetic algorithm, a placeholder looks up the crossover that it executes:
  - Create placeholder

```
Placeholder crossover = new Placeholder();
```

  - Set the name of operator to lookup

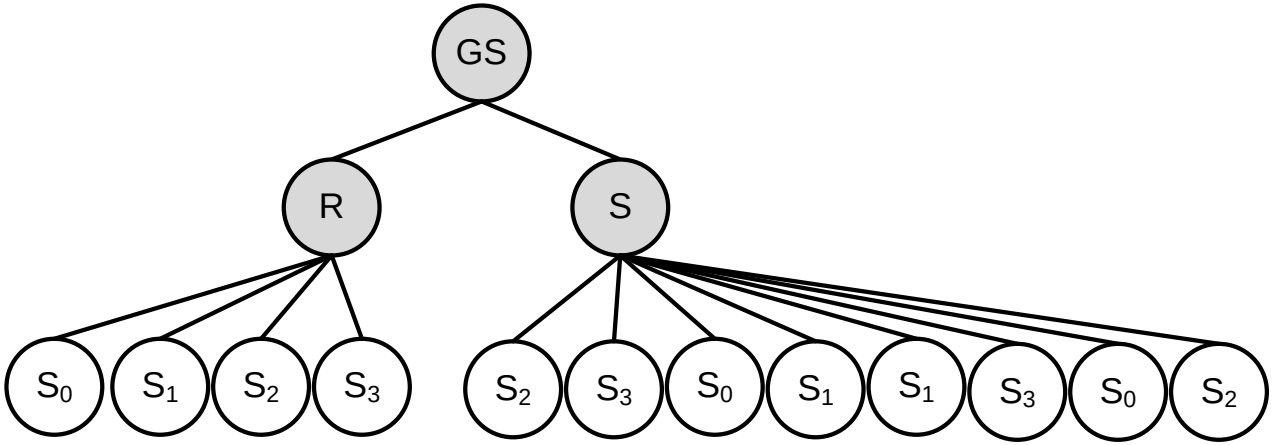
```
crossover.OperatorParameter.ActualName = "Crossover";
```

  - In the placeholder operator

```
OperationCollection next = new OperationCollection(base.Apply());
IOperator op = OperatorParameter.ActualValue;
if (op != null)
    next.Insert(0, ExecutionContext.CreateOperation(op));
return next;
```

Scopes

- A scope is a node in the scope tree
- Contains link to parent and sub-scopes
- Contains variables (e.g. solutions or their quality)
- Operators usually work on scopes (either directly or through parameters)
- Example - Selection:



Operators

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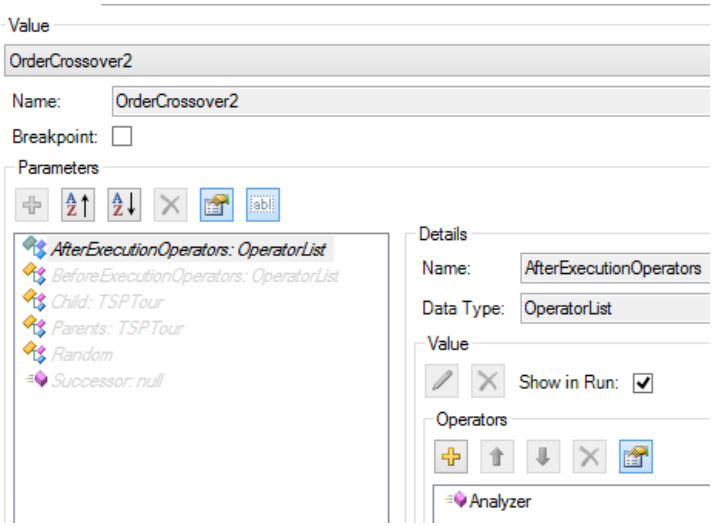
- Inherit from SingleSuccessorOperator
- Override the Apply() method
- Must return base.Apply()
  - Returns successor operation
- Use ExecutionContext to access scopes
- Or better: Use parameters to retrieve scopes, values from scopes or manipulate them

Instrumented Operators

- Inherit from InstrumentedOperator
- Override InstrumentedApply()
- Must return base.InstrumentedApply()
- Allows to configure before and after actions
- Useful for analyzers, additional functionality,… without changing the algorithm
- Think of aspect-oriented programming



Operators

A operator that increments a value from the scope by „Increment“

For easier access to parameter values

A parameter for retrieving „Value“ (default name, can be configure with ActualValue) from scope or parent scopes

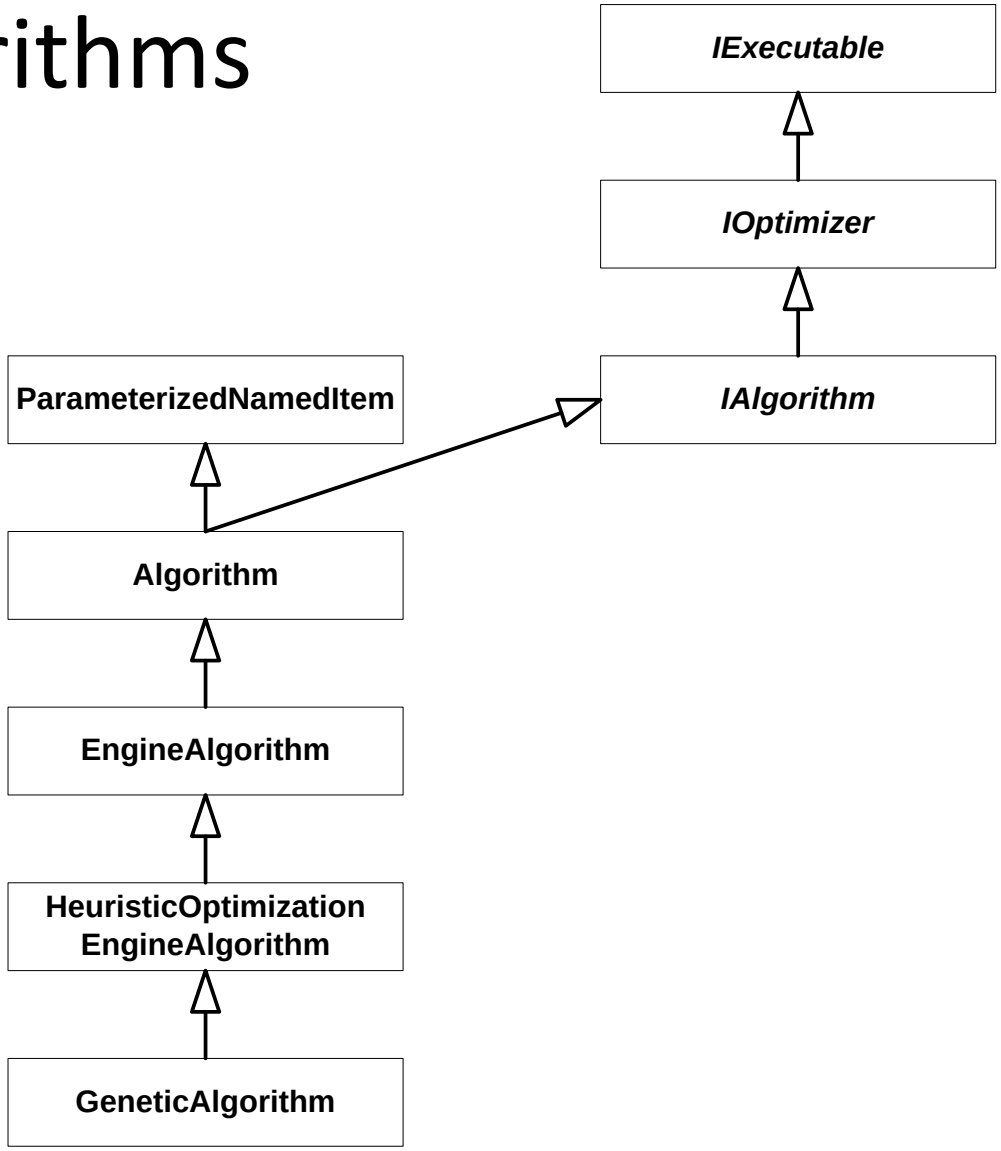
If the value is not found it can also be created in the scope

```
[Item("IntCounter", "An operator which increments an integer variable.")]
[StorableClass]
public sealed class IntCounter : SingleSuccessorOperator {
  public LookupParameter<IntValue> ValueParameter {
    get { return (LookupParameter<IntValue>)Parameters["Value"]; }
  }
  public ValueLookupParameter<IntValue> IncrementParameter {
    get { return (ValueLookupParameter<IntValue>)Parameters["Increment"]; }
  }
  public IntValue Increment {
    get { return IncrementParameter.Value; }
    set { IncrementParameter.Value = value; }
  }

  [StorableConstructor]
  private IntCounter(bool deserializing) : base(deserializing) { }
  private IntCounter(IntCounter original, Cloner cloner)
    : base(original, cloner) {
  }
  public IntCounter()
    : base() {
    Parameters.Add(new LookupParameter<IntValue>("Value", "The value which should be incremented."));
    Parameters.Add(new ValueLookupParameter<IntValue>("Increment", "The increment which is added to
the value.", new IntValue(1)));
  }

  public override IDeepCloneable Clone(Cloner cloner) {
    return new IntCounter(this, cloner);
  }

  public override IOperation Apply() {
    if (ValueParameter.ActualValue == null) ValueParameter.ActualValue = new IntValue();
    ValueParameter.ActualValue.Value += IncrementParameter.ActualValue.Value;
    return base.Apply();
  }
}
```

Algorithms and Problems

- Different ways how to implement algorithms and problems
- Algorithms
  - Flexible: Inherit from HeuristicOptimizationEngineAlgorithm
  - Easy: Inherit from BasicAlgorithm
- Problems
  - Flexible: Inherit from SingleObjectiveHeuristicOptimizationProblem
  - Easy: Inherit from [Single|Multi]ObjectiveBasicProblem

Base classes/interfaces for algorithms



Base classes/interfaces for algorithms

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- IExecutable (Executable):
  - Defines methods for starting, stopping, etc. of algorithms
- IOptimizer:
  - Contains a run collection
- IAlgorithm:
  - Contains a problem on which the algorithm is applied as well as a result
- Algorithm:
  - Base class, implements IAlgorithm
- EngineAlgorithm:
  - Extensions for execution with an engine (operator graph, scope, engine)
- HeuristicOptimizationEngineAlgorithm:
  - Specifies problem: IHeuristicOptimizationProblem

What does an HL algorithm do?

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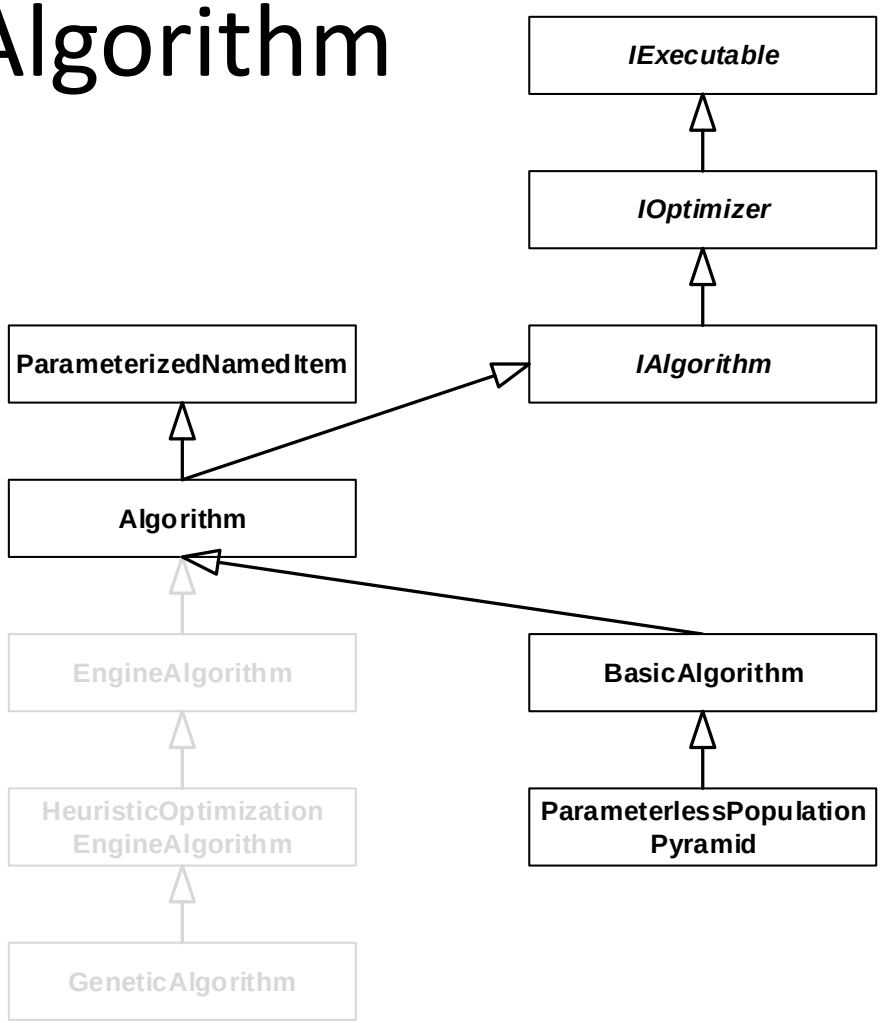
- Create operator graph of algorithm by chaining together operators (the actual algorithm)
- Offer user configuration options through parameters
- Discover operators from the Operators collection of the problem/encoding
- Parameterize/wire (react to changes in operators) operators where necessary

BasicAlgorithm

- Creating an operator graph can be quite tricky
- Wiring operators is error-prone
- BasicAlgorithms are
  - Easy to implement
  - No boilerplate code
  - Hard-coded (no operator graph)
  - Don’t support pause

Base classes/interfaces for BasicAlgorithm



BasicAlgorithm - Interface

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- Implement the Run method

```
protected override void Run(CancellationToken cancellationToken)
```

- Optional: Fix problem type

```
public override Type ProblemType {
   get { return typeof(BinaryProblem); }
}

public new BinaryProblem Problem {
   get { return (BinaryProblem)base.Problem; }
   set { base.Problem = value; }
}
```

Example – Random Search

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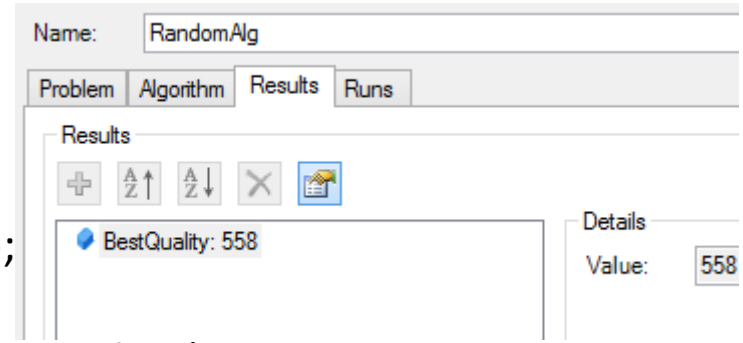
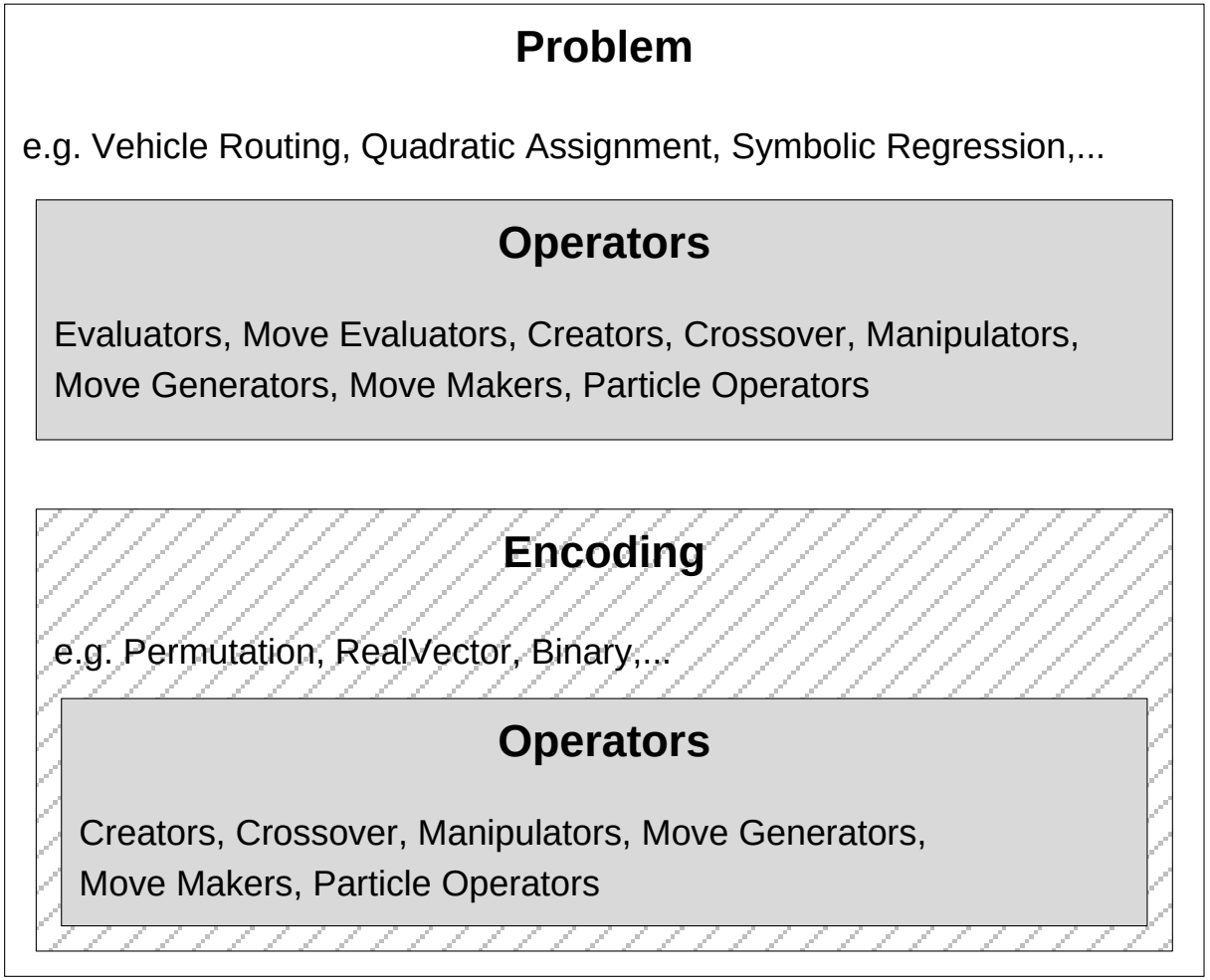
```
protected override void Run(CancellationToken cancellationToken)  {
  DoubleValue bestQuality = new DoubleValue(0.0);
  Results.Add(new Result("BestQuality", bestQuality));

  for(int i = 0; i < 100000; i++) {
    cancellationToken.ThrowIfCancellationRequested();

    BinaryVector b = new BinaryVector(Problem.Length, random);
    double curQuality = Problem.Evaluate(b, random);

    if(Problem.Maximization && curQuality > bestQuality.Value) {
      bestQuality.Value = curQuality;
    } else if(!Problem.Maximization && curQuality < bestQuality.Value) {
      bestQuality.Value = curQuality;
    }
  }
}
```



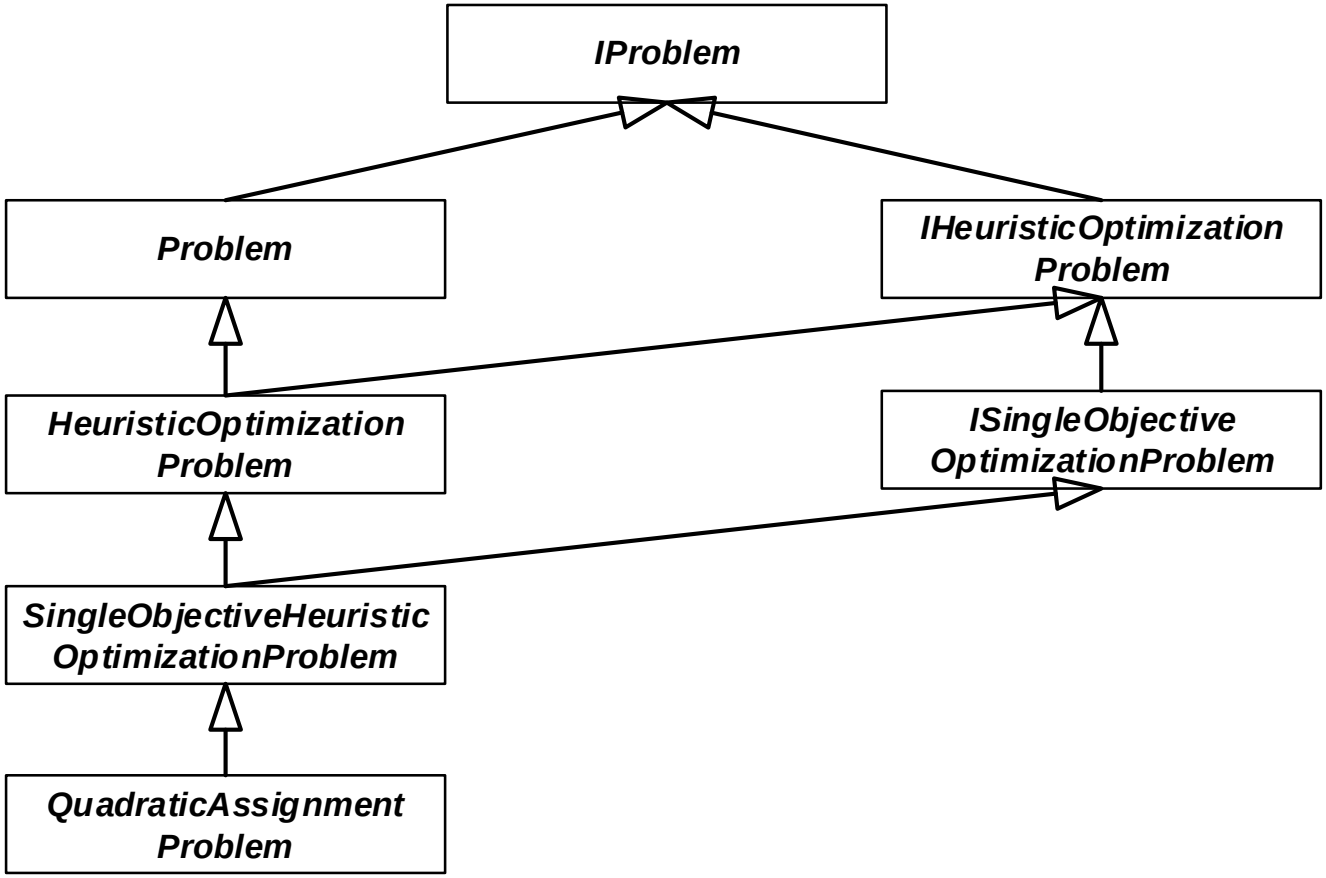
Problems

- Use encodings for representing solutions
- Encodings consist of solution candidate definitions and corresponding operators
- Problems contain
  - the evaluator
  - the solution creator
- Define maximization or minimization
- Contain the „problem data“ (e.g. a distance matrix, a simulation, a function definition), usually supplied by a ProblemInstanceProvider
- Can be single- or multi-objective
- Configured with parameters

Problem Architecture



Base classes/interfaces for problems



Base classes/interfaces for problems

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- IProblem:
  - Contains the operators collection; all operators that can be used by the problem, algorithm and user
- IHeuristicOptimizationProblem:
  - Defines solution creator and evaluator
- Problem, HeuristicOptimizationProblem and Single/MultiObjectiveHeuristicOptimizationProblem provide abstract base classes

Recap: What does a HL problem do?

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- Defines used encoding
- Defines single/multi objective
- Defines min/maximization
- Discovers correct operators
  - Are used by the algorithm
- Wires/parameterizes operators
- Loads problem data using a corresponding problem instance provider

BasicProblem

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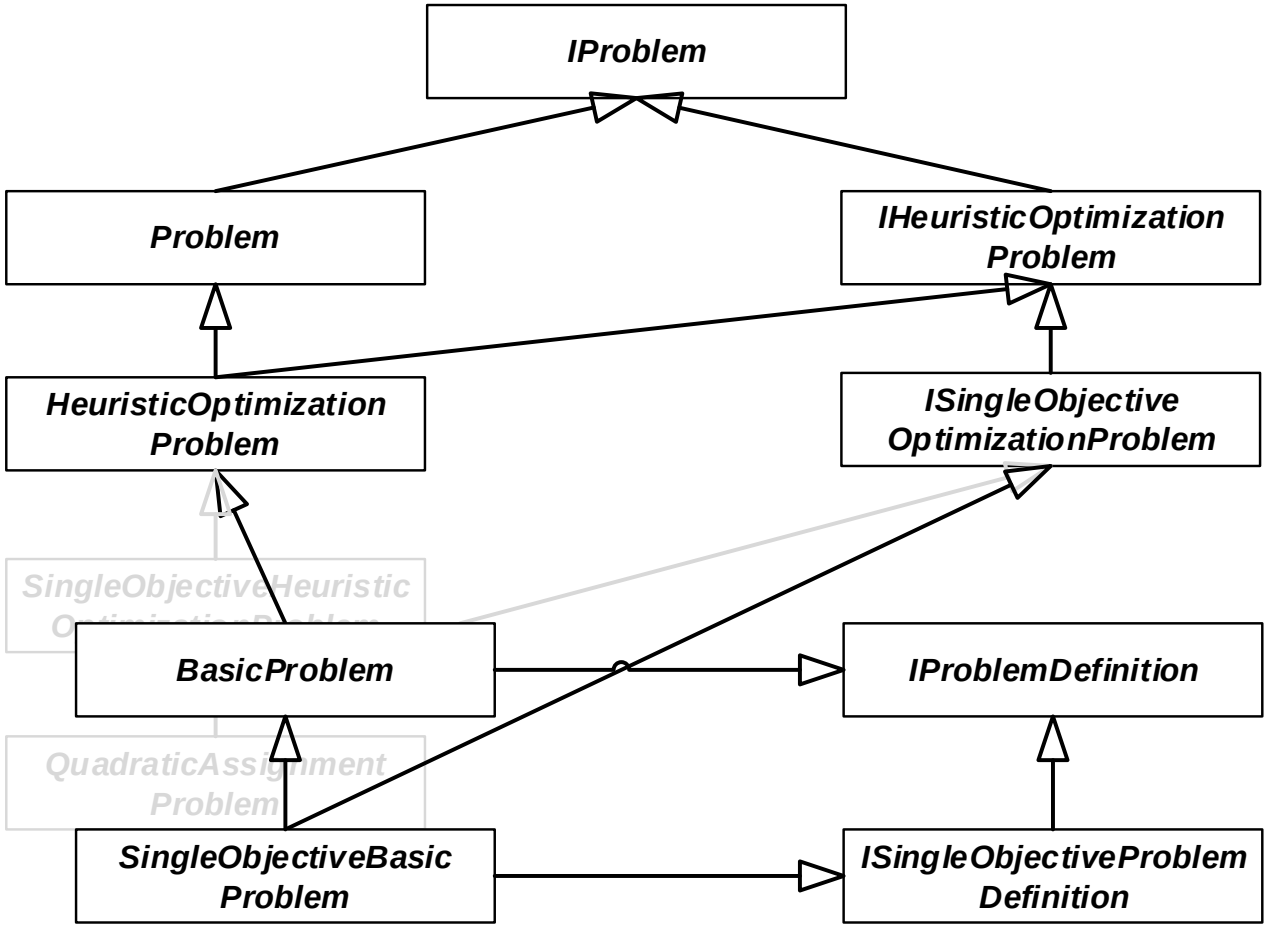
- Similar concept as BasicAlgorithm
- Makes implementing new problems easier
- No wireing/operators necessary
- Use automatic encoding configuration
- Don’t work with all algorithm types, e.g. algorithms that use very specific operators
  - Simulated Annealing
  - Scatter Search
  - Particle Swarm Optimization

Base classes/interfaces for BasicProblem



BasicProblem - Interface

- Define Encoding

```
MyNewProblem : SingleObjectiveBasicProblem<BinaryVectorEncoding>
```

- Define maximization or minimization

```
bool Maximization { get; }
```

- Evaluate a solution and return quality

```
double Evaluate(Individual individual, IRandom random);
```

BasicProblem - Interface

- Until now only GA variants can use the problem
- Implement neighbourhood function to also use trajectory-based metaheuristics

```
IEnumerable<Individual> GetNeighbors(Individual individual, IRandom random);
```

- Optional: Add analysis code for tracking results

```
void Analyze(Individual[] individuals, double[] qualities, ResultCollection results,
IRandom random);
```

BasicProblem – Example: OneMax

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```
class OneMaxProblem : SingleObjectiveBasicProblem<BinaryVectorEncoding> {
    public OneMaxProblem() { }
    [StorableConstructor]
    protected OneMaxProblem(bool deserializing) : base(deserializing) { }
    public OneMaxProblem(OneMaxProblem alg, Cloner cloner) : base(alg, cloner) { }
    public override IDeepCloneable Clone(Cloner cloner) {
      return new OneMaxProblem(this, cloner);
    }

    public override bool Maximization { get{ return true; } }

    public override double Evaluate(Individual individual, IRandom random) {
      return individual.BinaryVector().Count(b => b);
    }
  }
```

Useful Links

http://dev.heuristiclab.com/trac/hl/core/wiki/UsersHowtos

http://dev.heuristiclab.com/trac/hl/core/wiki/Publications

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http://www.youtube.com/heuristiclab