Evolutionary Computing Frameworks for Optimisation

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Agenda

• Artificial Intelligence and learning (*briefly*)
• Evolutionary Computation
• Frameworks
• Examples of application
• Discussion: practicalities
• Opportunities for collaboration?
• Pub!
**Assertion:** artificial intelligence is seen in software that appears to learn.

For instance, when we have loads of pre-existing data, software can learn to classify categories in the data (by rule induction, clustering, etc. etc.)

The software *learns a model* of data, based on known inputs and outputs.

The intention is to predict future outputs for unknown inputs.

**Question:** But what happens when there is no pre-existing data, or there is no access to pre-existing data?

Specifically, what happens when we know the sort of outputs we want (e.g. maximise this, minimise that…) but don’t know what sort of inputs that would achieve this?

This is *optimisation*… and it’s a different form of *learning*
**Question:** So how do we develop software to perform optimisation?

**Answer:** define a space of all the possible solutions, and then search through the space.

*Hmmm....* we could exhaustively enumerate over each solution, but search spaces get very big, very quickly...
Calculate the size of the search space

Given a Solution model, how many different combinations can it represent?

### Cloud balancing

**Model:**
- **Computer** → **Process**

**Search space:** \( c^p \)

<table>
<thead>
<tr>
<th># computers</th>
<th># processes</th>
<th>search space</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>100</td>
<td>300</td>
<td>( 10^{600} )</td>
</tr>
<tr>
<td>200</td>
<td>600</td>
<td>( 10^{1380} )</td>
</tr>
<tr>
<td>400</td>
<td>1200</td>
<td>( 10^{6967} )</td>
</tr>
</tbody>
</table>

### Traveling salesman (TSP)

**Model:**
- **linked list**

**Search space:** \( n! \)

### Course scheduling

**Model:**
- **Room** → **Period** → **Lecture**

**Search space:** \( (p \times r)^l \)

<table>
<thead>
<tr>
<th># periods</th>
<th># rooms</th>
<th># lectures</th>
<th>space</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>64</td>
</tr>
<tr>
<td>36</td>
<td>6</td>
<td>100</td>
<td>( 10^{233} )</td>
</tr>
<tr>
<td>36</td>
<td>18</td>
<td>400</td>
<td>( 10^{1124} )</td>
</tr>
<tr>
<td>36</td>
<td>36</td>
<td>800</td>
<td>( 10^{2490} )</td>
</tr>
</tbody>
</table>

http://www.optaplanner.org/blog/2014/03/27/searchSpaceSizeCalculation.png
So what to do?

Take inspiration from nature...
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• **Evolutionary Computation**
• Frameworks
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natural evolution

i.e. the change in the inherited characteristics of biological populations over successive generations.

environment

Selection of fittest individuals

sexual reproduction for population diversity / variety
Evolutionary Algorithms...

Not new...

- Alan Turin (1952)
  - “Computing Machinery and Intelligence” in *Mind* article hints at a “…genetical programming…”
- Alex Fraser (1957)
  - Computational simulation of natural evolution
- Fogel *et al.* (1966)
  - *Evolutionary programming* (finite state machines)
- Rechenburg (1973)
  - *Evolutionary Strategies*
- Holland (1975)
  - *Genetic Algorithms*
- Kosa (1992)
  - *Genetic Programming*

And many more
...via computational evolution

Representation of an “individual” solution
e.g. models, trees, arrays, code etc. etc.

initialise population at random
while( not done )
evaluate each individual
select parents
recombine pairs of parents
mutate new candidate individuals
select candidates for next generation
end while

initialise population at random
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end while

**Representation** of an “individual” solution
e.g. models, trees, arrays etc. etc.

There are two distinct needs....

1 - Enable effective variation and diversity (i.e. exploration)
2 - Enable fitness measures for evaluation (i.e. exploitation)
\[ 2 \cdot \pi + \left( (x + 3) - \frac{y}{5+1} \right) \]
initialise population at random
while( not done )
    evaluate each individual
    select parents
    recombine pairs of parents
    mutate new candidate individuals
    select candidates for next generation
end while

Fitness measures enable comparison of solution individuals in the population.

Typically,
Either maximise fitness e.g. quality, desirability, etc.

Or minimise cost e.g. time, resource, money, etc.

Evaluation can comprise:
• One fitness measure (single objective)
• 2 or 3 fitness measures (multi-objective)
• > 3 fitness measures (many-objective)
Challenges for Evolutionary Computation for developers?

• Searching for strategies rather than instances
• Exploiting many-core computing
• **Giving insight to software developers**
• Optimising compilation and deployment
• **‘AI-friendly’ software development and deployment**

Recent example...

https://arstechnica.co.uk/information-technology/2017/08/facebook-dynamic-analysis-software-sapienz/
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Evolutionary Optimisation Frameworks (EOFs)

“A set of software tools that provide a correct and reusable implementation of a set of metaheuristics, and the basic mechanisms to accelerate the implementation of its partner subordinate heuristics (possibly including solution encodings and technique-specific operators), which are necessary to solve a particular problem instance using techniques provided”

Evolutionary Optimisation Frameworks (EOFs)

• Adaptable search components (algorithms, operators...)
• Easy integration of problem-specific knowledge (fitness, solution encoding...)
• Mechanisms to configure and monitor the execution
• General utilities to conduct experiments
• Object-oriented paradigm
Evolutionary Optimisation Frameworks (EOFs)

**Advantages**
- Less coding effort
- Optimised code
- Additional utilities
- Programming environment

**Disadvantages**
- Which one?
- Learning curve
- External dependencies

# Some EOFs in C++

<table>
<thead>
<tr>
<th>NAME</th>
<th>WEB</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECF</td>
<td><a href="http://ecf.zemris.fer.hr/">http://ecf.zemris.fer.hr/</a></td>
<td>• Default parameter configuration&lt;br&gt;• Parallelism with MPI</td>
</tr>
<tr>
<td>1.4.2 (2017)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EO</td>
<td><a href="http://eodev.sourceforge.net/">http://eodev.sourceforge.net/</a></td>
<td>• Component-based design&lt;br&gt;• Parallelism with MPI and OpenMD</td>
</tr>
<tr>
<td>1.3.1 (2012)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>jMetalCpp</td>
<td><a href="https://github.com/jMetal/jMetalCpp">https://github.com/jMetal/jMetalCpp</a></td>
<td>• C++ (partial) version of jMetal&lt;br&gt;• Single and multi-objective problems</td>
</tr>
<tr>
<td>1.7 (2016)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MALLBA</td>
<td><a href="http://neo.lcc.uma.es/software/mallba/">http://neo.lcc.uma.es/software/mallba/</a></td>
<td>• Exact, heuristic and hybrid algorithms&lt;br&gt;• Minimum inheritance/virtual methods</td>
</tr>
<tr>
<td>2.0 (2009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open BEAGLE</td>
<td><a href="https://github.com/chgagne/beagle">https://github.com/chgagne/beagle</a></td>
<td>• Configuration files&lt;br&gt;• Advanced EC models (co-evolution)</td>
</tr>
<tr>
<td>3.0.3 (2007)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OptFrame</td>
<td><a href="https://sourceforge.net/projects/optframe/">https://sourceforge.net/projects/optframe/</a></td>
<td>• Local search and EC algorithms&lt;br&gt;• Support for MPI and MapReduce</td>
</tr>
<tr>
<td>2.2 (2017)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ParadisEO</td>
<td><a href="http://paradiseo.gforge.inria.fr/">http://paradiseo.gforge.inria.fr/</a></td>
<td>• Four modules: EO, MO, MOEO, SMP&lt;br&gt;• Parallel and distributed algorithms</td>
</tr>
<tr>
<td>2.0.1 (2012)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Some EOFS in Java/C#

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<tr>
<th>NAME</th>
<th>WEB</th>
<th>CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECJ</td>
<td><a href="https://cs.gmu.edu/~eclab/projects/ecj/">https://cs.gmu.edu/~eclab/projects/ecj/</a></td>
<td>• Variety of search algorithms&lt;br&gt;• Documentation and contributions</td>
</tr>
<tr>
<td>EvA</td>
<td><a href="http://www.ra.cs.uni-tuebingen.de/software/eva2/">http://www.ra.cs.uni-tuebingen.de/software/eva2/</a></td>
<td>• Includes a GUI&lt;br&gt;• Integration with MATLAB</td>
</tr>
<tr>
<td>HeuristicLab</td>
<td><a href="http://dev.heuristiclab.com/">http://dev.heuristiclab.com/</a></td>
<td>• Plugin-based architecture&lt;br&gt;• Complete graphical environment</td>
</tr>
<tr>
<td>3.3.14 (2016)</td>
<td><a href="http://dev.heuristiclab.com/">http://dev.heuristiclab.com/</a></td>
<td></td>
</tr>
<tr>
<td>JCLEC</td>
<td><a href="http://jclec.sourceforge.net/">http://jclec.sourceforge.net/</a></td>
<td>• Easy integration of user-defined code&lt;br&gt;• Machine learning algorithms</td>
</tr>
<tr>
<td>jMetal</td>
<td><a href="https://jmetal.github.io/jMetal/">https://jmetal.github.io/jMetal/</a></td>
<td>• Focused on multi-objective problems&lt;br&gt;• Recent algorithms and benchmarks</td>
</tr>
<tr>
<td>5.3 (2017)</td>
<td><a href="https://jmetal.github.io/jMetal/">https://jmetal.github.io/jMetal/</a></td>
<td></td>
</tr>
<tr>
<td>MOEA Fram.</td>
<td><a href="http://moeaframework.org/">http://moeaframework.org/</a></td>
<td>• Catalogue of multi-objective methods&lt;br&gt;• Well documented and tested code</td>
</tr>
<tr>
<td>Opt4J</td>
<td><a href="http://opt4j.sourceforge.net/">http://opt4j.sourceforge.net/</a></td>
<td>• Highly modular design&lt;br&gt;• Includes a GUI</td>
</tr>
</tbody>
</table>
Some other EOFs

- DEAP (Python)
  - https://github.com/DEAP
- GEATbx (Matlab)
  - http://www.geatbx.com/
- Pygmo (Python)
  - http://esa.github.io/pygmo/
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Java Class Library for Evolutionary Computation (JCLEC)

Java and open source

High-level programming style
- Interface-oriented design
- Design patterns

Extension modules
- Multi-objective algorithms
- Machine learning algorithms

Easy integration of new code
- Configuration with XML files

Visual environment (beta)

Java Reflection
Java Class Library for Evolutionary Computation (JCLEC)

initialise population at random
while( not done )
  evaluate each individual
  select parents
  recombine pairs of parents
  mutate new candidate individuals
  select candidates for next generation
end while

IProvider

getSpecies(): ISpecies
getEvaluator(): IEvaluator
getGeneration(): int
getInhabitants(): List<IIndividual>

IPopulation

generate(): List<IIndividual>

IIndividual

getFitness(): IFitness
setFitness(IFitness): void
copy(): IIndividual
equals(): boolean

IFitness

getValue(): double
setValue(double): void
isAcceptable(): boolean
copy(): IFitness

ISpecies

createIndividual(T[]): IIndividual

IProvider

provide(int): List<IIndividual>

IPopulation

getSpecies(): ISpecies
getEvaluator(): IEvaluator
getGeneration(): int
getInhabitants(): List<IIndividual>

IIndividual

getFitness(): IFitness
setFitness(IFitness): void
copy(): IIndividual
equals(): boolean

IFitness

getValue(): double
setValue(double): void
isAcceptable(): boolean
copy(): IFitness

ISpecies

createIndividual(T[]): IIndividual
Java Class Library for Evolutionary Computation (JCLEC)

 initialise population at random

while( not done )
   evaluate each individual
   select parents
   recombine pairs of parents
   mutate new candidate individuals
   select candidates for next generation
end while

IAlgorithm
execute(): void
pause(): void
terminate(): void
addListener(IAlgorithmListener): void
removeListener(IAlgorithmListener): void

PopulationAlgorithm
doInit(): void
doSelection(): void
doGeneration(): void
doReplacement(): void
doControl(): void

IAlgorithmListener

algorithmStarted(AlgorithmEvent): void
algorithmCompleted(AlgorithmEvent): void

IEvaluator
evaluate(List<IIndividual>): void
getNumberOfEvaluations(): int
initialise population at random
while( not done )
    evaluate each individual
    select parents
    recombine pairs of parents
    mutate new candidate individuals
    select candidates for next generation
end while

ISelector

select(List<IIndividual>): List<IIndividual>
select(List<IIndividual>, int): List<IIndividual>
select(List<IIndividual>, int, boolean): List<IIndividual>

IRecombinator

recombine(List<IIndividual>): List<IIndividual>

IMutator

mutate(List<IIndividual>): List<IIndividual>
Java Class Library for Evolutionary Computation (JCLEC)

<experiment>
  <process algorithm-type="net.sf.jclec.algorithm.classic.SGE">
    <rand-gen-factory type="net.sf.jclec.util.random.RanecuFactory" seed="123"/>
    <population-size>100</population-size>
    <max-of-generations>100</max-of-generations>
    <species type="net.sf.jclec.binarray.BinArrayIndividualSpecies"
      genotype-length="100"/>
    <evaluator type="tutorial.Knapsack">
      (...)
    </evaluator>
    <provider type="net.sf.jclec.binarray.BinArrayCreator"/>
    <parents-selector type="net.sf.jclec.selector.TournamentSelector">
      <tournament-size>2</tournament-size>
    </parents-selector>
    <recombinator type="net.sf.jclec.binarray.rec.UniformCrossover"
      rec-prob="0.9" />
    <mutator type="net.sf.jclec.binarray.mut.OneLocusMutator" mut-prob="0.2" />
    <listener type="net.sf.jclec.listener.PopulationReporter">
      <report-frequency>10</report-frequency>
      <report-on-file>true</report-on-file>
      <save-complete-population>false</save-complete-population>
      <report-title>Knapsack</report-title>
    </listener>
  </process>
</experiment>
Java Class Library for Evolutionary Computation (JCLEC)

VisualJCLEC webpage
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Got to find the right sort of problem...
What? Allocations, permutations, sequences, etc.
Why? for optimisation, insight discovery

Got to find the right scale of problem...
small problems can be solved with exhaustive search.
so generally large scale problems that can’t be solved otherwise

Just getting something that’s ‘good enough’ can be great!
often can’t prove that you’ve got the single best solution (single objective)
can never prove this for multi/many objective problems

Benchmarking performance – few agreed, standard benchmarks
evolutionary computation OK if execution in ‘reasonable time’?
some comparative surveys available

What happens after you’ve evolved a population of ‘optimal’ solutions?
which one(s) do you select? the developer has to choose?
so could the developer be involved – programmer intuition??

Anything else??
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• Pub!
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• Examples of application
• Discussion: practicalities
• Opportunities for collaboration?
• Pub! ...Brewdog?? Emyr?