DM841

Discrete Optimization

Working Environment

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Outline

1. Working Environment

2. Random Numbers

Outline

Building a Working Environment

What will you need during the project? How will you organize it? How will you make things work together?

- `src/` code that implements the algorithm (likely, several versions)
- `bin/` place where to put your executables
- `data/` input: Instances for the solver, parameters to guide the solver
- `scripts/` code that runs batches of experiments or parses files
- `log/` other log files produced by the run of the algorithm
- `res/` output: The result, the performance measurements
- `r/` analysis tools: statistics, data analysis, visualization
- `doc/` or `tex/` journal/report: A record of your experiments and findings, together with description of the algorithms.
- `Makefile` compiles the sources in `src` and puts the executables in `bin`.
- `README` explains how to compile, test and run the program. Eventually, it explains differences among versions.

$\rightsquigarrow$ organize everything like if you had to reproduce the same results in a few years from now.

Suggested organization


```
CPRN\
 |   src\
 |   data\
 |   res\
 |   log\
 |   doc\
 |   bin\
 |-  README
```

Example

Input controls on command line

```
xyz --main::instance ins1.txt --main::output-file log.txt --main::seed 12 > data.log
```

Output on stdout, self-describing

```
#stat instance.in 30 90
seed: 9897868
Parameter1: 30
Parameter2: A
Read instance. Time: 0.016001
begin try 1
best 0 col 22 time 0.004000 iter 0 par_iter 0
best 3 col 21 time 0.004000 iter 0 par_iter 0
best 1 col 21 time 0.004000 iter 0 par_iter 0
best 0 col 21 time 0.004000 iter 1 par_iter 1
best 6 col 20 time 0.004000 iter 3 par_iter 1
best 4 col 20 time 0.004000 iter 4 par_iter 2
best 2 col 20 time 0.004000 iter 6 par_iter 4
exit iter 7 time 1.000062
end try 1
```

Example

If a single program that implements many heuristics

- proceed for new versions but take old versions with a journal in archive.
  Consider using a version control system (that is: git).
- use command line parameters to choose among the heuristics
- Python: argparse (or older `getopt`, `optparse`)
  C: `getopt`, `getopt_long`, opag (option parser generator)
  Java: package `org.apache.commons.cli`
  EasyLocal: boost libraries
- use identifying labels in naming file outputs
  Example:
  `c0010.i0002.t0001.s02010.log`

Example

- You will need:
  multiple runs, multiple instances, multiple classes and multiple algorithms.
  Arrange this outside of your program: ➨ unix scripts (eg, bash one line program)

- Parse outputfiles:
  Example

  ```
  grep #stat * | cut -f 2 -d " "
  ```

  See http://www.gnu.org/software/coreutils/manual/ for shell tools.

- Data in form of matrix or data frame goes directly into R imported by `read.table()`, untouched by human hands!

```
alg instance     run sol time
ROS le450_15a.col 3 21 0.00267
ROS le450_15b.col 3 21 0
ROS le450_15d.col 3 31 0.00267
RLF le450_15a.col 3 17 0.00533
RLF le450_15b.col 3 16 0.008
...
```

Text Editor

- `vim` (Vi IMproved)
- `emacs`, visual code, jupyter-lab, spyder3, eclipse
- Integrated development environment. Choose your favourite:
  `http://en.wikipedia.org/wiki/Integrated_development_environment`

Graphics

Visualization helps understanding

- Problem visualization (matplotlib, networkx, graphviz)
- Algorithm animation
- Results visualization: recommended R (more on this later)
- Run time profiling

Testing and Debugging

Manual testing (modus tollens/ponens, ablation)

- Print at run time
- Debug in `spyder3` or other IDE
- Plot the development of
  - best visited solution quality
  - current solution quality

  over time and compare with other features of the algorithm.
- Take it well: it is like a detective job

Be Suspicious – Unit Testing Development

Automatic testing

- Check the correctness of your solutions at output everytime you do refactoring or new versions.
- edge cases: test of arguments or inputs that lead to undefined cases
- useful as silent documentation on the use of the code
- coverage: did things work before a change or was a certain aspect never tested?

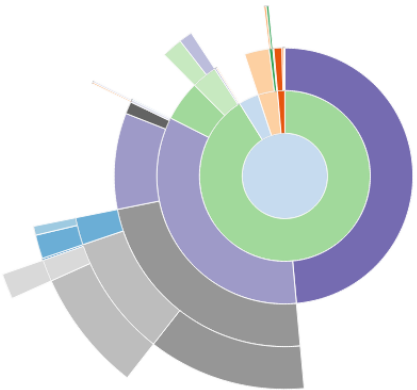
In Python, `assert` throws `AssertionError` unless `__debug__` is set to `false` by starting Python with an `-O` option.
In Python, module `unittest`: tests as methods of a Test class.
automates the calls to the test functions

Code Optimization

- Profile time consumption per program components
  - under Linux and OSX: `gprof`
    1. add flag `-pg` in compilation
    2. run the program
    3. `gprof gmon.out > a.txt`
  - under OSX:
    - Instruments
  - Java VM profilers (plugin for eclipse)
    http://visualvm.java.net/

Program Profiling in Python

cProfile
https://github.com/ymichael/cprofilev
https://jiffyclub.github.io/snakeviz/



Measuring Time

Execution time can be extremely short:

- put the statement to measure in a loop
- execute several times

Take minumum measured time to make sure other processes running on the computer do not influence the measured result too much.

In Python, module `timeit`
The timer object has a function `repeat` that takes two parameters
`repeat` number of overall repetitions
`number` number of iterations in the loop

Measuring Memory Consumption

- In Unix (and MacOs) `top`
- In Python, `python -m memory_profiler myscript` and `memprof` (for time dependent analysis) https://pypi.python.org/pypi/memory_profiler

Software Development

Extreme Programming & Scrum

Planning

Release planning creates the schedule • Make frequent small releases • The project is divided into iterations • Publish early, revise often

Designing

Simplicity • No functionality is added early • Refactor: eliminate unused functionality and redundancy

Coding

Code must be written to agreed standards • Code the unit test first • All production code is pair programmed • Leave optimization till last • No overtime • Pair programming

Testing

All code must have unit tests • All code must pass all unit tests before it can be released • When a bug is found tests are created

Development of Heuristics

- Model
- implement
- experiment
- fail
- think
- try again!

Outline

Random Numbers

Carachtersitics of a good pseudo-random generator
(from stochastic simulation)

- long period
- uniform unbiased distribution
- uncorrelated (time series analysis)
- efficient

Suggested: MRG32k3a by L'Ecuyer http://www.iro.umontreal.ca/~lecuyer/

Ideal Random Shuffle

Let's consider a sequence of n elements: $\{e_1, e_2, \dots e_n\}$.
The ideal random shuffle is a permutation chosen uniformly at random from the set of all possible $n!$ permutations.

- π_1 is uniformly randomly chosen among $\{e_1, e_2, \dots e_n\}$.
- π_2 is uniformly randomly chosen among $\{e_1, e_2, \dots e_n\} - \{\pi_1\}$.
- π_3 is uniformly randomly chosen among $\{e_1, e_2, \dots e_n\} - \{\pi_1, \pi_2\}$
- ...

Joint probability of $(\pi_1, \pi_2 \dots \pi_n)$ is $\frac{1}{n} \cdot \frac{1}{n-1} \cdot \dots 1 = \frac{1}{n!}$

```
long int* Random::generate_random_array(const int& size) {
   long int  i, j, help;
   long int  *v = new long int[size];
   for ( i = 0 ; i < size; i++ )
     v[i] = i;
   for ( i = 0 ; i < size-1 ; i++) {
     j = (long int) ( ranU01( ) * (size - i));
     help = v[i];
     v[i] = v[i+j];
     v[i+j] = help;
   }
   return v; }
```

Reservoir Sampling

How to select an element at random from a sequence of n elements where n is unknown?

- Keep the first item in memory.
- When the i-th item arrives (for $i > 1$):
  - with probability $1/i$, keep the new item (discard the old one)
  - with probability $1 - 1/i$ keep the old item (ignore the new one)

Probability of an element to be selected:

$$\Pr(\text{being selected once}) \cdot \Pr(\text{not being swapped later}) = 1 \cdot \prod_{i=2}^{n} (1 - \frac{1}{i})$$

Extension:
How to select a sample of k elements from a sequence S of unknown length?

- Keep the first k items in memory.
- When the ith item arrives (for $i > k$):
  - with probability k/i, keep the new item (discard an old one, selecting which to replace at random, each with chance 1/k)
  - with probability $1 - k/i$, keep the old items (ignore the new one)

For the first element of the sequence the probability of being selected is:

$$\Pr(\text{being selected first time}) \cdot \prod_{i=k+1}^{|S|} \Pr(\text{not being swapped}) = 1 \cdot \prod_{i=k+1}^{|S|} \left(1 - \frac{k}{i} \cdot \frac{1}{k}\right)$$

where

$$\Pr(\text{not being swapped}) = 1 - \Pr(\text{swapping exactly that one}) = 1 - \frac{k}{i}\frac{1}{k}$$

$$\Pr(\text{not being swapped}) = \Pr(\text{not swapping}) + p(\text{swapping one of the others}) = \left(1 - \frac{k}{i}\right) + \left(\frac{k}{i}\frac{k-1}{k}\right)$$

Implementation:

```
//  S has items to sample, R will contain the result
ReservoirSample(S[1..n], R[1..k])
  // fill the reservoir array
  for i = 1 to k
      R[i] := S[i]

  // replace elements with gradually decreasing probability
  for i = k+1 to n
    j := random(1, i)   // important: inclusive range
    if j <= k
        R[j] := S[i]
```