

Algorithms and Complexity

The Knapsack 0-1 problem

Petros Exarchos

Summary:

This is a report regarding the project creation proceedings, focused on analysing the purpose of the project, the structure of the code and the solutions implemented to solve the Knapsack 0-1 problem.

Furthermore various performance results are presented for each use-case.

Project Goal:

The goal of this project is to provide a programmatic solution to the knapsack 0-1 problem in c#. The end result (application) prioritizes on providing accessibility and comprehension of the given tools as well as to cover multiple use-cases.

Additionally multiple programing methods are used to solve problems (Dynamic programing, Recursive programing, Google-OrTools solver) and provide solutions and performance results using both pre-generated problems along with user specified.

The code structure was designed to support convenience in readability and allow easy optimization and testing of methods and classes.

Code Structure:

(1). David Pisinger modified generator: The application uses a modified version of the pseudorandom knapsack problem generation made by David Pisinger in C in 1994. The code has been modified to produce 320 knapsack problems of various sizes and is included in the program in the form of a DLL, created using Dev-Cpp 5.11.

(2). Main(): The application consists of one main thread designed to perform particular tasks based on user input, as many times as the user wants. All the tasks (as methods) are implemented on the same class as Main() and operate using functions and properties from other classes (as objects).

(3) InputHandler.cs : A class responsible on handling user-input, console printing (mostly), file creation, and file parsing. It is used on all use-cases as every problem solved by the application algorithms is provided via text file.

(4) Knapsack.cs : Default application knapsack 0-1 problem solver. The solution provides two ways of approaching problems. Either using Dynamic programming or Recursive programming. Both algorithms provide the same result but in dramatically different execution times. DP solution time complexity is (nW) . REC solution time complexity is (2^N) .

(5) GoogleOrToolsSolver.cs : A Dynamic programming knapsack 0-1 solver solution provided by the Or-Tools library.

(6) Xunit_UnitTests.cs : A solution created for the sole purpose of testing the reliability and consistency of the application. The solution have been created using the Xunit framework for Visual Studio Code.

Performance Results:

Computers used:

Computer 1: win10 64bit, 4gb ram ddr3, intel core i5-2430M 2.4Ghz

Computer 2: win10 64bit, 16gb ram ddr4, AMD Ryzen 5 2400G 3.6Ghz

(1). Using standard problems (github repo) (Random Order) (First 50 samples):

Computer 1 results:

Solved Test No:1 App result: 21538 execT: 10ms - OrTools result: 21538 execT: 15ms
Solved Test No:2 App result: 30553 execT: 18ms - OrTools result: 30553 execT: 43ms
Solved Test No:3 App result: 42821 execT: 29ms - OrTools result: 42821 execT: 84ms
Solved Test No:4 App result: 45810 execT: 33ms - OrTools result: 45810 execT: 125ms
Solved Test No:5 App result: 50973 execT: 31ms - OrTools result: 50973 execT: 187ms
Solved Test No:6 App result: 10713 execT: 7ms - OrTools result: 10713 execT: 8ms
Solved Test No:7 App result: 20438 execT: 15ms - OrTools result: 20438 execT: 35ms
Solved Test No:8 App result: 28814 execT: 32ms - OrTools result: 28814 execT: 65ms
Solved Test No:9 App result: 36285 execT: 32ms - OrTools result: 36285 execT: 124ms
Solved Test No:10 App result: 41106 execT: 30ms - OrTools result: 41106 execT: 142ms
Solved Test No:11 App result: 9388 execT: 7ms - OrTools result: 9388 execT: 22ms
Solved Test No:12 App result: 17535 execT: 13ms - OrTools result: 17535 execT: 60ms
Solved Test No:13 App result: 27192 execT: 23ms - OrTools result: 27192 execT: 107ms
Solved Test No:14 App result: 33697 execT: 24ms - OrTools result: 33697 execT: 163ms
Solved Test No:15 App result: 40603 execT: 31ms - OrTools result: 40603 execT: 248ms
Solved Test No:16 App result: 8998 execT: 9ms - OrTools result: 8998 execT: 2ms
Solved Test No:17 App result: 16965 execT: 19ms - OrTools result: 16965 execT: 9ms
Solved Test No:18 App result: 26502 execT: 31ms - OrTools result: 26502 execT: 40ms
Solved Test No:19 App result: 32887 execT: 28ms - OrTools result: 32887 execT: 89ms
Solved Test No:20 App result: 39693 execT: 35ms - OrTools result: 39693 execT: 114ms
Solved Test No:21 App result: 2722 execT: 1ms - OrTools result: 2722 execT: 1ms
Solved Test No:22 App result: 3403 execT: 1ms - OrTools result: 3403 execT: 4ms
Solved Test No:23 App result: 4142 execT: 2ms - OrTools result: 4142 execT: 10ms
Solved Test No:24 App result: 4819 execT: 3ms - OrTools result: 4819 execT: 13ms
Solved Test No:25 App result: 4976 execT: 3ms - OrTools result: 4976 execT: 21ms
Solved Test No:26 App result: 1008 execT: 1ms - OrTools result: 1008 execT: 1ms
Solved Test No:27 App result: 1811 execT: 1ms - OrTools result: 1811 execT: 2ms
Solved Test No:28 App result: 2473 execT: 1ms - OrTools result: 2473 execT: 6ms
Solved Test No:29 App result: 3566 execT: 2ms - OrTools result: 3566 execT: 11ms
Solved Test No:30 App result: 4411 execT: 3ms - OrTools result: 4411 execT: 19ms
Solved Test No:31 App result: 1222 execT: 1ms - OrTools result: 1222 execT: 2ms
Solved Test No:32 App result: 2211 execT: 1ms - OrTools result: 2211 execT: 6ms
Solved Test No:33 App result: 3062 execT: 1ms - OrTools result: 3062 execT: 8ms
Solved Test No:34 App result: 4220 execT: 2ms - OrTools result: 4220 execT: 15ms
Solved Test No:35 App result: 5343 execT: 3ms - OrTools result: 5343 execT: 23ms
Solved Test No:36 App result: 832 execT: 1ms - OrTools result: 832 execT: 0ms
Solved Test No:37 App result: 1631 execT: 1ms - OrTools result: 1631 execT: 0ms
Solved Test No:38 App result: 2352 execT: 2ms - OrTools result: 2352 execT: 2ms

Solved Test No:39 App result: 3420 execT: 2ms - OrTools result: 3420 execT: 6ms
Solved Test No:40 App result: 4443 execT: 3ms - OrTools result: 4443 execT: 13ms
Solved Test No:41 App result: 11175 execT: 4ms - OrTools result: 11175 execT: 5ms
Solved Test No:42 App result: 14912 execT: 5ms - OrTools result: 14912 execT: 19ms
Solved Test No:43 App result: 19728 execT: 9ms - OrTools result: 19728 execT: 39ms
Solved Test No:44 App result: 22929 execT: 11ms - OrTools result: 22929 execT: 67ms
Solved Test No:45 App result: 26463 execT: 15ms - OrTools result: 26463 execT: 91ms
Solved Test No:46 App result: 5403 execT: 3ms - OrTools result: 5403 execT: 5ms
Solved Test No:47 App result: 10083 execT: 6ms - OrTools result: 10083 execT: 16ms
Solved Test No:48 App result: 14512 execT: 9ms - OrTools result: 14512 execT: 35ms
Solved Test No:49 App result: 18494 execT: 12ms - OrTools result: 18494 execT: 54ms
Solved Test No:50 App result: 21826 execT: 15ms - OrTools result: 21826 execT: 84ms

Computer 2 results:

Solved Test No:1 App result: 21538 execT: 4ms - OrTools result: 21538 execT: 8ms
Solved Test No:2 App result: 30553 execT: 48ms - OrTools result: 30553 execT: 23ms
Solved Test No:3 App result: 42821 execT: 12ms - OrTools result: 42821 execT: 47ms
Solved Test No:4 App result: 45810 execT: 25ms - OrTools result: 45810 execT: 258ms
Solved Test No:5 App result: 50973 execT: 16ms - OrTools result: 50973 execT: 417ms
Solved Test No:6 App result: 10713 execT: 3ms - OrTools result: 10713 execT: 5ms
Solved Test No:7 App result: 20438 execT: 6ms - OrTools result: 20438 execT: 19ms
Solved Test No:8 App result: 28814 execT: 10ms - OrTools result: 28814 execT: 37ms
Solved Test No:9 App result: 36285 execT: 14ms - OrTools result: 36285 execT: 220ms
Solved Test No:10 App result: 41106 execT: 16ms - OrTools result: 41106 execT: 297ms
Solved Test No:11 App result: 9388 execT: 3ms - OrTools result: 9388 execT: 26ms
Solved Test No:12 App result: 17535 execT: 6ms - OrTools result: 17535 execT: 40ms
Solved Test No:13 App result: 27192 execT: 10ms - OrTools result: 27192 execT: 71ms
Solved Test No:14 App result: 33697 execT: 13ms - OrTools result: 33697 execT: 106ms
Solved Test No:15 App result: 40603 execT: 17ms - OrTools result: 40603 execT: 430ms
Solved Test No:16 App result: 8998 execT: 3ms - OrTools result: 8998 execT: 1ms
Solved Test No:17 App result: 16965 execT: 5ms - OrTools result: 16965 execT: 5ms
Solved Test No:18 App result: 26502 execT: 9ms - OrTools result: 26502 execT: 59ms
Solved Test No:19 App result: 32887 execT: 13ms - OrTools result: 32887 execT: 114ms
Solved Test No:20 App result: 39693 execT: 16ms - OrTools result: 39693 execT: 194ms
Solved Test No:21 App result: 2722 execT: 0ms - OrTools result: 2722 execT: 0ms
Solved Test No:22 App result: 3403 execT: 0ms - OrTools result: 3403 execT: 2ms
Solved Test No:23 App result: 4142 execT: 0ms - OrTools result: 4142 execT: 4ms
Solved Test No:24 App result: 4819 execT: 1ms - OrTools result: 4819 execT: 7ms
Solved Test No:25 App result: 4976 execT: 1ms - OrTools result: 4976 execT: 12ms
Solved Test No:26 App result: 1008 execT: 0ms - OrTools result: 1008 execT: 0ms
Solved Test No:27 App result: 1811 execT: 0ms - OrTools result: 1811 execT: 1ms
Solved Test No:28 App result: 2473 execT: 0ms - OrTools result: 2473 execT: 4ms
Solved Test No:29 App result: 3566 execT: 1ms - OrTools result: 3566 execT: 7ms
Solved Test No:30 App result: 4411 execT: 1ms - OrTools result: 4411 execT: 34ms
Solved Test No:31 App result: 1222 execT: 0ms - OrTools result: 1222 execT: 1ms
Solved Test No:32 App result: 2211 execT: 21ms - OrTools result: 2211 execT: 3ms
Solved Test No:33 App result: 3062 execT: 0ms - OrTools result: 3062 execT: 5ms
Solved Test No:34 App result: 4220 execT: 1ms - OrTools result: 4220 execT: 10ms
Solved Test No:35 App result: 5343 execT: 1ms - OrTools result: 5343 execT: 15ms
Solved Test No:36 App result: 832 execT: 0ms - OrTools result: 832 execT: 0ms

Solved Test No:37 App result: 1631 execT: 0ms - OrTools result: 1631 execT: 0ms
 Solved Test No:38 App result: 2352 execT: 0ms - OrTools result: 2352 execT: 1ms
 Solved Test No:39 App result: 3420 execT: 1ms - OrTools result: 3420 execT: 4ms
 Solved Test No:40 App result: 4443 execT: 1ms - OrTools result: 4443 execT: 8ms
 Solved Test No:41 App result: 11175 execT: 2ms - OrTools result: 11175 execT: 3ms
 Solved Test No:42 App result: 14912 execT: 2ms - OrTools result: 14912 execT: 12ms
 Solved Test No:43 App result: 19728 execT: 5ms - OrTools result: 19728 execT: 82ms
 Solved Test No:44 App result: 22929 execT: 6ms - OrTools result: 22929 execT: 38ms
 Solved Test No:45 App result: 26463 execT: 8ms - OrTools result: 26463 execT: 55ms
 Solved Test No:46 App result: 5403 execT: 1ms - OrTools result: 5403 execT: 3ms
 Solved Test No:47 App result: 10083 execT: 3ms - OrTools result: 10083 execT: 10ms
 Solved Test No:48 App result: 14512 execT: 5ms - OrTools result: 14512 execT: 63ms
 Solved Test No:49 App result: 18494 execT: 6ms - OrTools result: 18494 execT: 33ms
 Solved Test No:50 App result: 21826 execT: 9ms - OrTools result: 21826 execT: 51ms

(2). Using D. Pisinger pseudorandom generator with seed offset (7) seven (last 50 samples)

Computer 1 results:

Solved Test No:270 App result: 21506 execT: 90ms - OrTools result: 21506 execT: 2257ms
 Solved Test No:271 App result: 6251 execT: 16ms - OrTools result: 6251 execT: 226ms
 Solved Test No:272 App result: 11216 execT: 32ms - OrTools result: 11216 execT: 599ms
 Solved Test No:273 App result: 16527 execT: 57ms - OrTools result: 16527 execT: 1443ms
 Solved Test No:274 App result: 20851 execT: 80ms - OrTools result: 20851 execT: 1767ms
 Solved Test No:275 App result: 25508 execT: 121ms - OrTools result: 25508 execT: 2766ms
 Solved Test No:276 App result: 4201 execT: 17ms - OrTools result: 4201 execT: 12ms
 Solved Test No:277 App result: 8346 execT: 38ms - OrTools result: 8346 execT: 93ms
 Solved Test No:278 App result: 13037 execT: 63ms - OrTools result: 13037 execT: 328ms
 Solved Test No:279 App result: 16751 execT: 64ms - OrTools result: 16751 execT: 866ms
 Solved Test No:280 App result: 20948 execT: 180ms - OrTools result: 20948 execT: 1499ms
 Solved Test No:281 App result: 58221 execT: 84ms - OrTools result: 58221 execT: 748ms
 Solved Test No:282 App result: 84725 execT: 158ms - OrTools result: 84725 execT: 2463ms
 Solved Test No:283 App result: 99618 execT: 240ms - OrTools result: 99618 execT: 4685ms
 Solved Test No:284 App result: 114680 execT: 321ms - OrTools result: 114680 execT: 8034ms
 Solved Test No:285 App result: 122118 execT: 394ms - OrTools result: 122118 execT: 11740ms
 Solved Test No:286 App result: 25685 execT: 101ms - OrTools result: 25685 execT: 527ms
 Solved Test No:287 App result: 45855 execT: 151ms - OrTools result: 45855 execT: 1613ms
 Solved Test No:288 App result: 70566 execT: 295ms - OrTools result: 70566 execT: 4609ms
 Solved Test No:289 App result: 91118 execT: 343ms - OrTools result: 91118 execT: 6909ms
 Solved Test No:290 App result: 107544 execT: 408ms - OrTools result: 107544 execT: 9772ms
 Solved Test No:291 App result: 23291 execT: 105ms - OrTools result: 23291 execT: 914ms
 Solved Test No:292 App result: 43513 execT: 154ms - OrTools result: 43513 execT: 2827ms
 Solved Test No:293 App result: 65547 execT: 253ms - OrTools result: 65547 execT: 5438ms
 Solved Test No:294 App result: 86441 execT: 322ms - OrTools result: 86441 execT: 8797ms
 Solved Test No:295 App result: 112415 execT: 425ms - OrTools result: 112415 execT: 13004ms
 Solved Test No:296 App result: 21301 execT: 108ms - OrTools result: 21301 execT: 81ms

Solved Test No:297 App result: 40613 execT: 168ms - OrTools result: 40613 execT: 537ms
Solved Test No:298 App result: 61987 execT: 253ms - OrTools result: 61987 execT: 1778ms
Solved Test No:299 App result: 82351 execT: 328ms - OrTools result: 82351 execT: 4216ms
Solved Test No:300 App result: 107865 execT: 451ms - OrTools result: 107865 execT: 8073ms
Solved Test No:301 App result: 114892 execT: 184ms - OrTools result: 114892 execT: 1601ms
Solved Test No:302 App result: 165368 execT: 330ms - OrTools result: 165368 execT: 5012ms
Solved Test No:303 App result: 203986 execT: 501ms - OrTools result: 203986 execT: 9798ms
Solved Test No:304 App result: 229545 execT: 767ms - OrTools result: 229545 execT: 19533ms
Solved Test No:305 App result: 252270 execT: 882ms - OrTools result: 252270 execT: 27427ms
Solved Test No:306 App result: 51549 execT: 176ms - OrTools result: 51549 execT: 1206ms
Solved Test No:307 App result: 97172 execT: 325ms - OrTools result: 97172 execT: 3929ms
Solved Test No:308 App result: 135861 execT: 494ms - OrTools result: 135861 execT: 7286ms
Solved Test No:309 App result: 178071 execT: 692ms - OrTools result: 178071 execT: 13846ms
Solved Test No:310 App result: 219550 execT: 888ms - OrTools result: 219550 execT: 21707ms
Solved Test No:311 App result: 44414 execT: 159ms - OrTools result: 44414 execT: 1885ms
Solved Test No:312 App result: 87619 execT: 336ms - OrTools result: 87619 execT: 5501ms
Solved Test No:313 App result: 125037 execT: 477ms - OrTools result: 125037 execT: 10510ms
Solved Test No:314 App result: 174411 execT: 651ms - OrTools result: 174411 execT: 16868ms
Solved Test No:315 App result: 223655 execT: 869ms - OrTools result: 223655 execT: 25354ms
Solved Test No:316 App result: 42384 execT: 213ms - OrTools result: 42384 execT: 150ms
Solved Test No:317 App result: 84779 execT: 333ms - OrTools result: 84779 execT: 1034ms
Solved Test No:318 App result: 121487 execT: 481ms - OrTools result: 121487 execT: 3136ms
Solved Test No:319 App result: 170351 execT: 646ms - OrTools result: 170351 execT: 7942ms
Solved Test No:320 App result: 219115 execT: 842ms - OrTools result: 219115 execT: 16434ms

Computer 2 results:

Solved Test No:270 App result: 1703 execT: 0ms - OrTools result: 1703 execT: 0ms
Solved Test No:271 App result: 3159 execT: 0ms - OrTools result: 3159 execT: 0ms
Solved Test No:272 App result: 498 execT: 0ms - OrTools result: 498 execT: 0ms
Solved Test No:273 App result: 1154 execT: 0ms - OrTools result: 1154 execT: 0ms
Solved Test No:274 App result: 1038 execT: 0ms - OrTools result: 1038 execT: 0ms
Solved Test No:275 App result: 1637 execT: 0ms - OrTools result: 1637 execT: 0ms
Solved Test No:276 App result: 213 execT: 0ms - OrTools result: 213 execT: 0ms
Solved Test No:277 App result: 3079 execT: 0ms - OrTools result: 3079 execT: 0ms
Solved Test No:278 App result: 2287 execT: 0ms - OrTools result: 2287 execT: 0ms

Solved Test No:279 App result: 4089 execT: 0ms - OrTools result: 4089 execT: 0ms
Solved Test No:280 App result: 3183 execT: 0ms - OrTools result: 3183 execT: 0ms
Solved Test No:281 App result: 4649 execT: 0ms - OrTools result: 4649 execT: 0ms
Solved Test No:282 App result: 4213 execT: 0ms - OrTools result: 4213 execT: 0ms
Solved Test No:283 App result: 1207 execT: 0ms - OrTools result: 1207 execT: 0ms
Solved Test No:284 App result: 2047 execT: 0ms - OrTools result: 2047 execT: 0ms
Solved Test No:285 App result: 2864 execT: 0ms - OrTools result: 2864 execT: 0ms
Solved Test No:286 App result: 2561 execT: 0ms - OrTools result: 2561 execT: 0ms
Solved Test No:287 App result: 64 execT: 0ms - OrTools result: 64 execT: 0ms
Solved Test No:288 App result: 5336 execT: 0ms - OrTools result: 5336 execT: 0ms
Solved Test No:289 App result: 1030 execT: 0ms - OrTools result: 1030 execT: 0ms
Solved Test No:290 App result: 2183 execT: 0ms - OrTools result: 2183 execT: 0ms
Solved Test No:291 App result: 2338 execT: 0ms - OrTools result: 2338 execT: 0ms
Solved Test No:292 App result: 2703 execT: 0ms - OrTools result: 2703 execT: 0ms
Solved Test No:293 App result: 4800 execT: 0ms - OrTools result: 4800 execT: 0ms
Solved Test No:294 App result: 1000 execT: 0ms - OrTools result: 1000 execT: 0ms
Solved Test No:295 App result: 2153 execT: 0ms - OrTools result: 2153 execT: 0ms
Solved Test No:296 App result: 2288 execT: 0ms - OrTools result: 2288 execT: 0ms
Solved Test No:297 App result: 2633 execT: 0ms - OrTools result: 2633 execT: 0ms
Solved Test No:298 App result: 79 execT: 0ms - OrTools result: 79 execT: 0ms
Solved Test No:299 App result: 20755 execT: 4ms - OrTools result: 20755 execT: 31ms
Solved Test No:300 App result: 581 execT: 0ms - OrTools result: 581 execT: 0ms
Solved Test No:301 App result: 918 execT: 0ms - OrTools result: 918 execT: 0ms
Solved Test No:302 App result: 957 execT: 0ms - OrTools result: 957 execT: 0ms
Solved Test No:303 App result: 1180 execT: 0ms - OrTools result: 1180 execT: 0ms
Solved Test No:304 App result: 1087 execT: 0ms - OrTools result: 1087 execT: 0ms
Solved Test No:305 App result: 298 execT: 0ms - OrTools result: 298 execT: 0ms
Solved Test No:306 App result: 461 execT: 0ms - OrTools result: 461 execT: 0ms
Solved Test No:307 App result: 696 execT: 0ms - OrTools result: 696 execT: 0ms
Solved Test No:308 App result: 960 execT: 0ms - OrTools result: 960 execT: 0ms
Solved Test No:309 App result: 130 execT: 0ms - OrTools result: 130 execT: 0ms
Solved Test No:310 App result: 1108 execT: 0ms - OrTools result: 1108 execT: 0ms
Solved Test No:311 App result: 419 execT: 0ms - OrTools result: 419 execT: 0ms
Solved Test No:312 App result: 708 execT: 0ms - OrTools result: 708 execT: 0ms
Solved Test No:313 App result: 1000 execT: 0ms - OrTools result: 1000 execT: 0ms
Solved Test No:314 App result: 1234 execT: 0ms - OrTools result: 1234 execT: 0ms
Solved Test No:315 App result: 1455 execT: 0ms - OrTools result: 1455 execT: 0ms
Solved Test No:316 App result: 239 execT: 0ms - OrTools result: 239 execT: 0ms
Solved Test No:317 App result: 398 execT: 0ms - OrTools result: 398 execT: 0ms
Solved Test No:318 App result: 660 execT: 0ms - OrTools result: 660 execT: 0ms
Solved Test No:319 App result: 824 execT: 0ms - OrTools result: 824 execT: 0ms
Solved Test No:320 App result: 233 execT: 0ms - OrTools result: 233 execT: 0ms

(3). Comparison of a problem solved with DP and REC programming:

Computer 1 results:

App result: 5376 execT: 5ms - OrTools result: 5376 execT: 1ms
App (Recursive) result: 5376 execT: 5388ms

Computer 2 results:

App result: 5376 execT: 0ms - OrTools result: 5376 execT: 0ms
App (Recursive) result: 5376 execT: 3834ms

Sources:

David Pisinger Generator: <http://hjemmesider.diku.dk/~pisinger/generator.c>
0-1 Knapsack problem solver: <https://www.geeksforgeeks.org/0-1-knapsack-problem-dp-10/>
xUnit framework : <https://xunit.net/>
Google Or-Tools : <https://developers.google.com/optimization/install> &
NuGet Package Version : <https://www.nuget.org/packages/Google.OrTools/7.4.7247>