## 70068

## SCHEDULING AND

## RESOURCE ALLOCATION

## **Coursework: Image Processing Workflow**

Submission Deadline: 24 November 2021

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## 1.0 Job Processing Times

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| --- | --- | --- | --- | --- | --- |
| *Table 1: Job Processing Times obtained from Azure VM.* | | | | | |
| Filter Name | *mean* | std dev | Filter Name | *mean* | std dev |
| s | s | s | s |
| vii | 21.1218 | ± 0.8585 | muse | 13.2213 | ± 1.0760 |
| emboss | 1.9645 | ± 0.0729 | night | 25.7214 | ± 1.0185 |
| blur | 6.0954 | ± 0.1257 | onnx | 5.8572 | ± 0.4845 |
| wave | 17.5761 | ± 1.2900 |  |  |  |

## 2.0 Search Algorithms Intermediate Results

### **2.1 Least Cost Last (LCL)**

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| --- | --- | --- | --- | --- | --- | --- | --- |
| *Table 2: Intermediate Results following the Least Cost Last (LCL) algorithm.* | | | | | | | |
| K | Jobs with n=0 | Tj (s) | Selected  S[k] | K | Jobs with n=0 | Tj (s) | Selected S[k] |
| 34 | **wave**\_6 | **261** | wave\_6 | 17 | emboss\_1, emboss\_3, **onnx\_3,** wave\_2 | 139, 86, **84**, 123 | onnx\_3 |
| 33 | **onnx\_1**, emboss\_1, emboss\_3 | **123**, 276, 223 | onnx\_1 | 16 | emboss\_1, **emboss\_3**, wave\_2 | 134, **81,** 118 | emboss\_3 |
| 32 | **muse\_1**, emboss\_1, emboss\_3 | **206**, 270, 217 | muse\_1 | 15 | emboss\_1, **vii\_1**, wave\_2 | 132, **0**, 116 | vii\_1 |
| 31 | emboss\_1, **blur\_1,** emboss\_3 | 257, **182**, 204 | blur\_1 | 14 | emboss\_1, **blur\_2**, wave\_2 | 111, **0**, 95 | blur\_2 |
| 30 | emboss\_1, emboss\_3, blur\_4, **emboss\_4,** blur\_6 | 251, 198, 16, **0,** 128 | emboss\_4 | 13 | emboss\_1, **wave\_1**, wave\_2 | 104, **0**, 88 | wave\_1 |
| 29 | emboss\_1, emboss\_3, blur\_4, **onnx\_2**, blur\_6 | 249, 196, 14, **0**, 126 | onnx\_2 | 12 | emboss\_1, **blur\_3**, wave\_2 | 87, **0**, 71 | blur\_3 |
| 28 | emboss\_1, emboss\_3, **blur\_4**, onnx\_3, blur\_6 | 243, 190, **8**, 188, 120 | blur\_4 | 11 | emboss\_1, **wave\_2** | 81, **65** | wave\_2 |
| 27 | emboss\_1, emboss\_3, onnx\_3, **blur\_5**, blur\_6 | 237, 184, 182, **0**, 114 | blur\_5 | 10 | emboss\_1, **wave\_3** | 63, **0** | wave\_3 |
| 26 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **blur\_6** | 231, 178, 176, 215, **108** | blur\_6 | 9 | emboss\_1, **wave\_4** | 46, **0** | wave\_4 |
| 25 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **night\_1** | 225, 172, 170, 209, **34** | night\_1 | 8 | emboss\_1, **emboss\_5**, emboss\_6 | 28, **0**, 0 | emboss\_5 |
| 24 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **muse\_2** | 199, 146, 144, 183, **0.6** | muse\_2 | 7 | emboss\_1, **onnx\_4**, emboss\_6 | 26, **0**, 0 | onnx\_4 |
| 23 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **emboss\_7** | 186, 133, 131, 170, **0** | emboss\_7 | 6 | emboss\_1, **emboss\_6** | 20, **0** | emboss\_6 |
| 22 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **onnx\_6** | 184, 131, 129, 168, **58** | onnx\_6 | 5 | emboss\_1, **onnx\_5** | 18, **0** | onnx\_5 |
| 21 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **wave\_5** | 178, 125, 123, 162, **0** | wave\_5 | 4 | emboss\_1, **vii\_2** | 12, **0** | vii\_2 |
| 20 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **emboss\_8**, muse\_3 | 161, 108, 106, 145, **0,** 0 | emboss\_8 | 3 | **emboss\_1** | **0** | emboss\_1 |
| 19 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **muse\_3** | 159, 106, 104, 143, **0** | muse\_3 | 2 | **emboss\_2** | **0** | emboss\_2 |
| 18 | emboss\_1, emboss\_3, onnx\_3, wave\_2, **onnx\_7** | 145, 92, 90, 129, **61** | onnx\_7 | 1 | **onnx\_8** | **0** | onnx\_8 |

*\*Jobs with least cost (Tj) at each k and their Tj values have been bolded. Only whole numbers shown for simplicity.*

**Max Tardiness, Tj,max**: 261.2315s **Total Tardiness, :** 2242.916 **Schedule:** see data/lcl/lcl.csv or lcl.json

### **Tabu Search**

For this section, only the first 3 iterations are shown, as well as those where new optimums were found.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Table 3: Intermediate Results for Tabu Search (i) K=10.* | | | | |
| K | Candidate Swap Pair | (s) | Tabu List, | gbest |
| 1 | (onnx\_7, vii\_2) | 2566.5249 | [] | inf |
| 2 | (muse\_3, emboss\_8) | 2577.7817 | [(31, 22)] | 2566.5249 |
| 3 | (onnx\_7, emboss\_8) | 2581.6744 | [(31, 22), (30, 29)] | 2566.5249 |

**Total Tardiness, :** 2566.5249s **Best Schedule:** see data/tabu/tabu\_10.csv

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Table 4: Intermediate Results for Tabu Search (ii) K=100 (same as K=1000).* | | | | |
| K | Candidate Swap Pair | (s) | Tabu List, | gbest |
| 1 | (onnx\_7, vii\_2) | 2566.5249 | [] | inf |
| 2 | (muse\_3, emboss\_8) | 2577.7817 | [(31, 22)] | 2566.5249 |
| 3 | (onnx\_7, emboss\_8) | 2581.6744 | [(31, 22), (30, 29)] | 2566.5249 |
| 32 | (onnx\_7, wave\_3) | 2565.6938 | [(29, 17), (26, 16), (27, 16), (28, 16), (30, 16)] | 2566.5249 |
| 33 | (emboss\_8, wave\_3) | 2550.0822 | [(26, 16), (27, 16), (28, 16), (30, 16), (31, 16)] | 2565.6938 |
| 34 | (muse\_2, onnx\_3) | 2544.2250 | [(27, 16), (28, 16), (30, 16), (31, 16), (29, 16)] | 2550.0822 |
| 35 | (emboss\_7, onnx\_3) | 2538.3678 | [(28, 16), (30, 16), (31, 16), (29, 16), (25, 13)] | 2544.2250 |
| 36 | (onnx\_6, onnx\_3) | 2532.5106 | [(30, 16), (31, 16), (29, 16), (25, 13), (26, 13)] | 2538.3678 |
| 37 | (wave\_5, onnx\_3) | 2526.6534 | [(31, 16), (29, 16), (25, 13), (26, 13), (27, 13)] | 2532.5106 |
| 38 | (muse\_3, onnx\_3) | 2520.7962 | [(29, 16), (25, 13), (26, 13), (27, 13), (28, 13)] | 2526.6534 |
| 39 | (onnx\_7, onnx\_3) | 2514.9390 | [(25, 13), (26, 13), (27, 13), (28, 13), (30, 13)] | 2520.7962 |
| 40 | (emboss\_8, onnx\_3) | 2509.0818 | [(26, 13), (27, 13), (28, 13), (30, 13), (31, 13)] | 2514.9390 |
| 49 | (emboss\_7, wave\_2) | 2494.2148 | [(21, 13), (22, 13), (18, 13), (19, 13), (25, 15)] | 2509.0818 |
| 50 | (onnx\_6, wave\_2) | 2478.3229 | [(22, 13), (18, 13), (19, 13), (25, 15), (26, 15)] | 2494.2148 |
| 51 | (wave\_5, wave\_2) | 2460.7468 | [(18, 13), (19, 13), (25, 15), (26, 15), (27, 15)] | 2478.3229 |
| 52 | (muse\_3, wave\_2) | 2443.1707 | [(19, 13), (25, 15), (26, 15), (27, 15), (28, 15)] | 2460.7468 |
| 53 | (onnx\_7, wave\_2) | 2432.6242 | [(25, 15), (26, 15), (27, 15), (28, 15), (30, 15)] | 2443.1707 |
| 54 | (emboss\_8, wave\_2) | **2415.0481** | [(26, 15), (27, 15), (28, 15), (30, 15), (31, 15)] | 2432.6242 |

**Total Tardiness, :** 2415.0481s **Best Schedule:** see data/tabu/tabu\_100.csv

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Table 5: Intermediate Results for Tabu Search (iii) K=1000 (same as K=100).* | | | | |
| K | Candidate Swap Pair | (s) | Tabu List, | gbest |
| 1 | (onnx\_7, vii\_2) | 2566.5249 | [] | inf |
| 2 | (muse\_3, emboss\_8) | 2577.7817 | [(31, 22)] | 2566.5249 |
| 3 | (onnx\_7, emboss\_8) | 2581.6744 | [(31, 22), (30, 29)] | 2566.5249 |
| 32 | (onnx\_7, wave\_3) | 2565.6938 | [(29, 17), (26, 16), (27, 16), (28, 16), (30, 16)] | 2566.5249 |
| 33 | (emboss\_8, wave\_3) | 2550.0822 | [(26, 16), (27, 16), (28, 16), (30, 16), (31, 16)] | 2565.6938 |
| 34 | (muse\_2, onnx\_3) | 2544.2250 | [(27, 16), (28, 16), (30, 16), (31, 16), (29, 16)] | 2550.0822 |
| 35 | (emboss\_7, onnx\_3) | 2538.3678 | [(28, 16), (30, 16), (31, 16), (29, 16), (25, 13)] | 2544.2250 |
| 36 | (onnx\_6, onnx\_3) | 2532.5106 | [(30, 16), (31, 16), (29, 16), (25, 13), (26, 13)] | 2538.3678 |
| 37 | (wave\_5, onnx\_3) | 2526.6534 | [(31, 16), (29, 16), (25, 13), (26, 13), (27, 13)] | 2532.5106 |
| 38 | (muse\_3, onnx\_3) | 2520.7962 | [(29, 16), (25, 13), (26, 13), (27, 13), (28, 13)] | 2526.6534 |
| 39 | (onnx\_7, onnx\_3) | 2514.9390 | [(25, 13), (26, 13), (27, 13), (28, 13), (30, 13)] | 2520.7962 |
| 40 | (emboss\_8, onnx\_3) | 2509.0818 | [(26, 13), (27, 13), (28, 13), (30, 13), (31, 13)] | 2514.9390 |
| 49 | (emboss\_7, wave\_2) | 2494.2148 | [(21, 13), (22, 13), (18, 13), (19, 13), (25, 15)] | 2509.0818 |
| 50 | (onnx\_6, wave\_2) | 2478.3229 | [(22, 13), (18, 13), (19, 13), (25, 15), (26, 15)] | 2494.2148 |
| 51 | (wave\_5, wave\_2) | 2460.7468 | [(18, 13), (19, 13), (25, 15), (26, 15), (27, 15)] | 2478.3229 |
| 52 | (muse\_3, wave\_2) | 2443.1707 | [(19, 13), (25, 15), (26, 15), (27, 15), (28, 15)] | 2460.7468 |
| 53 | (onnx\_7, wave\_2) | 2432.6242 | [(25, 15), (26, 15), (27, 15), (28, 15), (30, 15)] | 2443.1707 |
| 54 | (emboss\_8, wave\_2) | **2415.0481** | [(26, 15), (27, 15), (28, 15), (30, 15), (31, 15)] | 2432.6242 |

**Total Tardiness, :** 2415.0481s **Best Schedule:** see data/tabu/tabu\_1000.csv

## 3.0 Azure VM Experiments

### **3.1 Results**

|  |  |  |
| --- | --- | --- |
| *Table 6: Measured total completion time and tardiness for different schedules.* | | |
| Schedule | total completion time, | total tardiness, |
| s | s |
| LCL | 305.8080 ± 3.1993 | 1223.8325 ± 45.5073 |
| Sinit (topological sort) | 309.0527 ± 0.7341 | 1794.3777 ± 18.7643 |
| Tabu with K=10 | 307.6739 ± 4.5760 | 1778.9092 ± 45.4836 |
| Tabu with K=100 | 305.0251 ± 3.4359 | 1592.0226 ± 33.1001 |
| Tabu with K=1000 | 307.6157 ± 3.5305 | 1624.4023 ± 38.4423 |

### **3.2 Comment on Tabu Search**

Tabu Search performance can definitely improve. Currently it performs poorer against LCL due to suboptimal parameters. As , the current threshold (=30) is too large, preventing tabu search from filtering through the search space efficiently. Instead, it just accepts the first candidate at each iteration. Through tuning threshold () and tabu list length (L) parameters, it was found that  **= 13**, **L = 9** at K=1000 could yield a significantly better schedule. This optimised schedule can be found in **data/tabu/tabu\_optimal.csv**, and has a **total tardiness = 2182.1186s**, better than those found in Section 2.0. Running this on the Azure VM, a 30% decrease in was observed:

|  |  |  |
| --- | --- | --- |
| *Table 7: Optimised tabu search result.* | | |
| Schedule | *total completion time,* | *total tardiness,* |
| s | s |
| Tabu Optimised (K = 1000, = 13 and L = 9) | 301.1290 ± 1.1092 | 1122.1753 ± 13.7929 |

Potentially better schedules could also be obtained by increasing K, as the algorithm is given more time to escape local optimums and reach a globally optimal solution. However, this can be computationally expensive and hence, this trade-off must be taken into account when devising the optimal schedule.