Todo list

Listing of Publications

This dissertation is based on the following publications, listed in chronological order:

Paper I Supervised Learning Linear Priority Dispatch Rules for Job-Shop Scheduling

Paper II Sampling Strategies in Ordinal Regression for Surrogate Assisted Evolutionary Optimization

Paper III Determining the Characteristic of Difficult Job Shop Scheduling Instances for a Heuristic Solution Method

Paper IV Evolutionary Learning of Weighted Linear Composite Dispatching Rules for Scheduling

Paper V Generating Training Data for Learning Linear Composite Dispatching Rules for Scheduling

These publications will be referenced throughout using their Roman numeral. The thesis is divided into two parts: *Prologue,* and *Papers*. The Prologue gives a coherent connection for the publications, and elaborates on chosen aspects. Whereas, Papers contains copies of the publications reprinted with permission from the publishers.

PROLOGUE

What is the use of a book, without pictures or conversations?

Alice

1 Something different

OFF WITH THEIR HEAD! Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

$$\zeta = \frac{1039}{\pi} \tag{1.1}$$

1.1 Cleverref

For an example of a full page figure, see Fig. 1.3. Figure 1.1 on the other hand is a smaller figure, inline with text. The `cleverref` package is very convenient, as it uses the same formatting throughout, i.e., not *Figure* vs. *figure* inconsistencies. You can also refer to your papers, e.g. Paper I*, with their roman numeral. Always calling `\cref`.

Nulla malesuada porttitor diam. Donec felis erat, congue non, volutpat at, tincidunt tristique, libero. Vivamus viverra fermentum felis. Donec nonummy pellentesque ante. Phasellus adipiscing semper elit. Proin fermentum massa ac quam. Sed diam turpis, molestie vitae, placerat a, molestie nec, leo. Maecenas lacinia. Nam ipsum ligula, eleifend at, accumsan nec, suscipit a, ipsum. Morbi blandit ligula feugiat magna. Nunc eleifend consequat lorem. Sed lacinia nulla vitae enim. Pellentesque tincidunt purus vel magna. Integer non enim. Praesent euismod nunc eu purus. Donec bibendum quam in tellus. Nullam cursus pulvinar lectus. Donec et mi. Nam vulputate metus eu enim. Vestibulum pellentesque felis eu massa.

1.2 First Paragraph

And now I begin my first chapter here ...

Here is an equation**:

$$CIF: \quad F_{\circ}^{j}(a) \quad = \quad \frac{1}{2\pi\iota}\oint_{\gamma}\frac{F_{\circ}^{j}(z)}{z-a}dz \tag{1.2}$$

Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellen-

*Update `endmatter/papers.tex`, `frontmatter/papers.tex` and `papers/papers.bib` to your publications.

**the notation is explained in the nomenclature section tesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, commodo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

You can also include pseudocode, such as in Alg. 1. Quisque ullamcorper placerat ipsum. Cras nibh. Morbi vel justo vitae lacus tincidunt ultrices. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. In hac habitasse platea dictumst. Integer tempus convallis augue. Etiam facilisis. Nunc elementum fermentum wisi. Aenean placerat. Ut imperdiet, enim sed gravida sollicitudin, felis odio placerat quam, ac pulvinar elit purus eget enim. Nunc vitae tortor. Proin tempus nibh sit amet nisl. Vivamus quis tortor vitae risus porta vehicula.

Fusce mauris. Vestibulum luctus nibh at lectus. Sed bibendum, nulla a faucibus semper, leo velit ultricies tellus, ac venenatis arcu wisi vel nisl. Vestibulum diam. Aliquam pellentesque, augue quis sagittis posuere, turpis lacus congue quam, in hendrerit risus eros eget felis. Maecenas eget erat in sapien mattis porttitor. Vestibulum porttitor. Nulla facilisi. Sed a turpis eu lacus commodo facilisis. Morbi fringilla, wisi in dignissim interdum, justo lectus sagittis dui, et vehicula libero dui cursus dui. Mauris tempor ligula sed lacus. Duis cursus enim ut augue. Cras ac magna. Cras nulla. Nulla egestas. Curabitur a leo. Quisque egestas wisi eget nunc. Nam feugiat lacus vel est. Curabitur consectetuer.

Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean faucibus pede eu ante. Praesent enim elit, rutrum at, molestie non, nonummy vel, nisl. Ut lectus eros, malesuada sit amet, fermentum eu, sodales cursus, magna. Donec eu purus. Quisque vehicula, urna sed ultricies auctor, pede lorem egestas dui, et convallis elit erat sed nulla. Donec luctus. Curabitur et nunc. Aliquam dolor odio, com-

Algorithm 1 Euclid's algorithm

```
procedure EUCLID(a, b)                          ▷ The g.c.d. of a and b
    r ← a mod b
    while r ≠ 0 do                              ▷ We have the answer if r is 0
        a ← b
        b ← r
        r ← a mod b
    end while
    return b                                    ▷ The gcd is b
end procedure
```

modo pretium, ultricies non, pharetra in, velit. Integer arcu est, nonummy in, fermentum faucibus, egestas vel, odio.

1.3 Mad Hatter's Tea Party

There are many examples of Job-Shop Scheduling Problem (JSP) for real-world application. However, for demonstration purposes, let's examine a hypothetical problem from the 18th century. Assume we are invited to the Mad Hatter's Tea Party in Wonderland illustrated in Fig. 1.1. There are four guests attending, namely: J_1) Alice; J_2) March Hare; J_3) Dormouse, and of course our host J_4) Mad Hatter. During these festivities, there are several things each member of the party has to perform. They all have to: M_1) have wine or pour tea; M_2) spread butter; M_3) get a haircut; M_4) check the time of the broken watch for themselves, and M_5) say what you mean, be it asking a riddle, telling a story, or singing a song to the group. Our guests are very particular creatures, and would like to do these task in a very specific order, e.g., March Hare insists on doing them in alphabetical order. And each would rather wait than breaking their habit. Moreover, they tend to be very absent-minded so each task takes them a different amount of time. Let's assume that their processing times and ordering are given in Table 1.1.

Unfortunately, Alice can't stay long. She must leave as soon as possible to play croquet with the Red Queen, and she mustn't be late for that very important date. Otherwise, it's off with someone's head! However, Alice, had a proper upbringing and won't leave the table until everyone has finished their tasks. How should the guests go about their tea-

Table 1.1: Example of 4×5 Job-Shop

Guest	Job	Machine ordering $\boldsymbol{\sigma}$					Processing times $\mathbf{p}$				
Alice	J_1	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~26~~	~~25~~	~~40~~	~~15~~	~~42~~
March Hare	J_2	~~1~~	**2**	3	4	5	~~18~~	**86**	86	68	84
Dormouse	J_3	~~1~~	~~3~~	**2**	4	5	~~20~~	**59**	~~23~~	33	96
Mad Hatter	J_4	~~4~~	~~3~~	**1**	5	2	**40**	47	~~55~~	~~13~~	99

party, in order for Alice to be on-time?

The problem faced by Alice and her new friends is in what order should they rotate their tasks between themselves so that they all finish as soon as possible? This can be considered as is a typical four-job and five-machine job-shop, where: our guests are the jobs; their tasks are the machines, and our objective is to minimise the makespan, i.e., when Alice can leave.

Let's assume we've come to the party, after 10 operations have already been made (i.e.

Figure 1.1: The Mad Hatter's Tea Party, from Alice's Adventures in Wonderland by Carroll (1865). Illustration by John Tenniel (1820-1914).

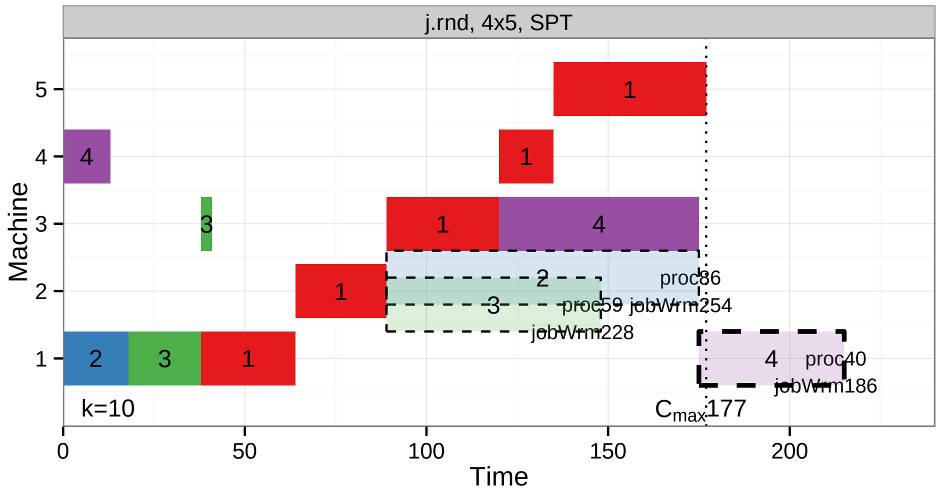


Figure 1.2: Gantt chart of a partial JSP schedule after 10 dispatches: Solid and dashed boxes represent $\boldsymbol{\chi}$ and $\mathcal{L}^{(11)}$, respectively. Current $C_{\max}$ denoted as dotted line.

strikeout entries in Table 1.1), by using the following job sequence,*

$$\boldsymbol{\chi} = \{\chi_i\}_{i=1}^{k-1} = \{J_4, J_2, J_3, J_3, J_1, J_1, J_1, J_1, J_1, J_4\} \tag{1.3}$$

hence currently, at step $k = 11$, the job-list is $\mathcal{L}^{(k)} = \{J_2, J_3, J_4\}$ indicating the 3 potential** jobs (i.e. denoted in bold in Table 1.1) to be dispatched, i.e., $\chi_k \in \mathcal{L}^{(k)}$.

Figure 1.2 illustrates the temporal partial schedule of the dispatching process as a Gantt-chart: *i)* numbers in the boxes represent the job identification j; *ii)* the width of the box illustrates the processing times for a given job for a particular machine M_a (on the vertical axis); *iii)* the dashed boxes represent the resulting partial schedule for when a particular job is scheduled next, and *iv)* the current $C_{\max}$ is denoted with a dotted line. Note, Fig. 1.4 displays how the initial schedules looked like, i form of a game-tree.

*In fact this is the sequence resulting from 10 dispatches following the SPT-rule, to be defined shortly.

**Alice is quite anxious to leave, so she has already completed everything, and therefore $J_1 \notin \mathcal{L}^{(11)}$.

Sed commodo posuere pede. Mauris ut est. Ut quis purus. Sed ac odio. Sed vehicula hendrerit sem. Duis non odio. Morbi ut dui. Sed accumsan risus eget odio. In hac habitasse platea dictumst. Pellentesque non elit. Fusce sed justo eu urna porta tincidunt. Mauris felis odio, sollicitudin sed, volutpat a, ornare ac, erat. Morbi quis dolor. Donec pellentesque, erat ac sagittis semper, nunc dui lobortis purus, quis congue purus metus ultricies tellus. Proin et quam. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Praesent sapien turpis, fermentum vel, eleifend faucibus, vehicula eu, lacus.

Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Donec odio elit, dictum in, hendrerit sit amet, egestas sed, leo. Praesent feugiat sapien aliquet odio. Integer vitae justo. Aliquam vestibulum fringilla lorem. Sed neque lectus, consectetuer at, consectetuer sed, eleifend ac, lectus. Nulla facilisi. Pellentesque eget lectus. Proin eu metus. Sed porttitor. In hac habitasse platea dictumst. Suspendisse eu lectus. Ut mi mi, lacinia sit amet, placerat et, mollis vitae, dui. Sed ante tellus, tristique ut, iaculis eu, malesuada ac, dui. Mauris nibh leo, facilisis non, adipiscing quis, ultrices a, dui.

Morbi luctus, wisi viverra faucibus pretium, nibh est placerat odio, nec commodo wisi enim eget quam. Quisque libero justo, consectetuer a, feugiat vitae, porttitor eu, libero. Suspendisse sed mauris vitae elit sollicitudin malesuada. Maecenas ultricies eros sit amet ante. Ut venenatis velit. Maecenas sed mi eget dui varius euismod. Phasellus aliquet volutpat odio. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Pellentesque sit amet pede ac sem eleifend consectetuer. Nullam elementum, urna vel imperdiet sodales, elit ipsum pharetra ligula, ac pretium ante justo a nulla. Curabitur tristique arcu eu metus. Vestibulum lectus. Proin mauris. Proin eu nunc eu urna hendrerit faucibus. Aliquam auctor, pede consequat laoreet varius, eros tellus scelerisque quam, pellentesque hendrerit ipsum dolor sed augue. Nulla nec lacus.

Figure 1.3 ***(following page)*:** This is a full page figure using the FPfigure command. It takes up the whole page and the caption appears on the preceding page. Its useful for large figures. Harvard's rules about full page figures are tricky, but you don't have to worry about it because we took care of it for you. For example, the full figure is supposed to have a title in the same style as the caption but without the actual caption. The caption is supposed to appear alone on the preceding page with no other text. You do't have to worry about any of that. We have modified the fltpage package to make it work. This is a lengthy caption and it clearly would not fit on the same page as the figure. Note that you should only use the FPfigure command in instances where the figure really is too large. If the figure is small enough to fit by the caption than it does not produce the desired effect. Good luck with your thesis. I have to keep writing this to make the caption really long. LaTex is a lot of fun. You will enjoy working with it. Good luck on your post doctoral life! I am looking forward to mine.

Figure 1.3: (continued)

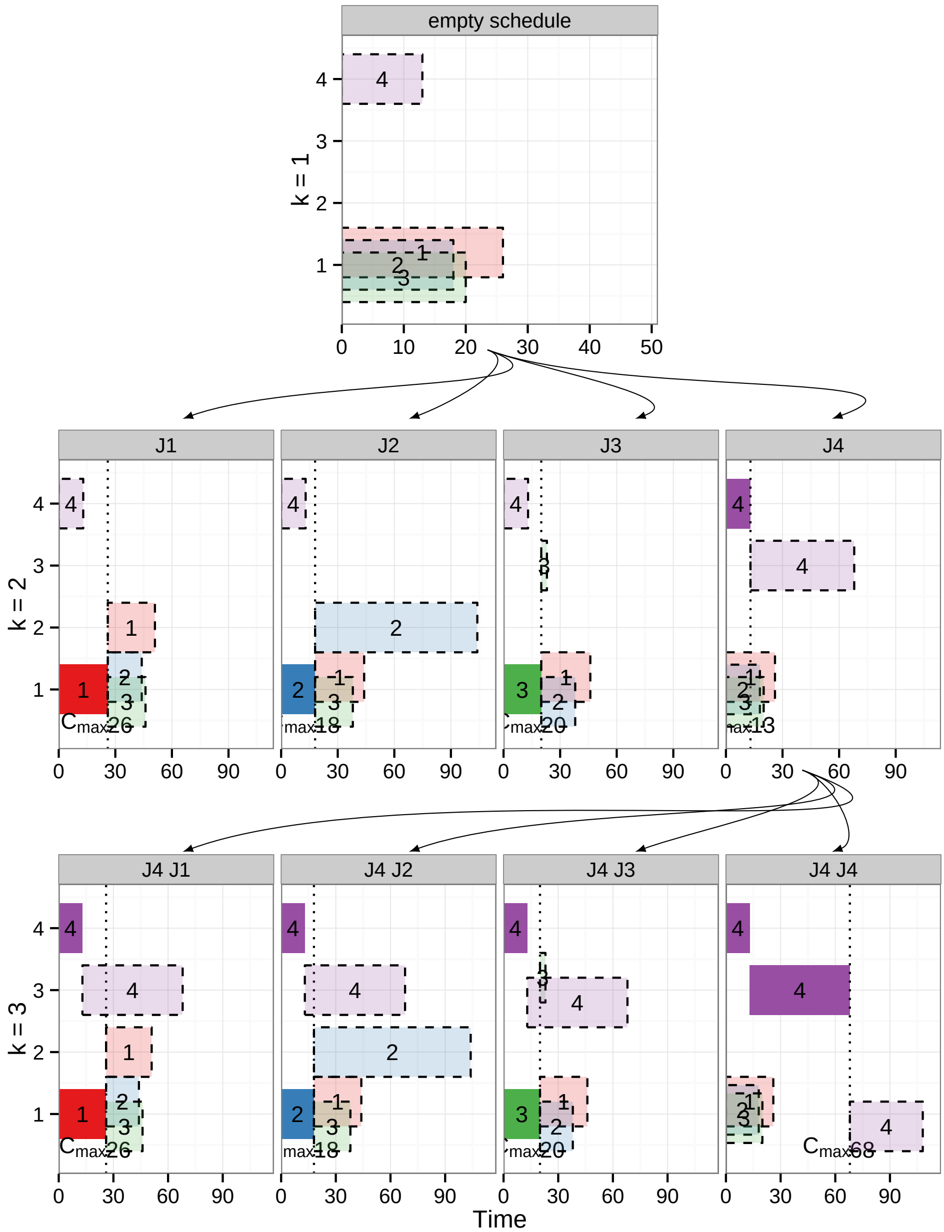


Figure 1.4: Using tikz over figures

A cat may look at a king. I've read that in some book, but I don't remember where.

Alice

References

L. Carroll. *Alice's Adventures in Wonderland*. Macmillan, 1865.

L. Carroll. *Through the Looking-Glass, and What Alice Found There*. Macmillan, 1871.

What is the use of a book, without pictures or conversations?

Alice

A

Test function suite

TEST FUNCTIONS f USED in **??** are defined $f : \mathbb{R}^d \mapsto \mathbb{R}$. All benchmark functions with the exception of **?** are described in **?**. They are summarized here for completeness. The original sources of the functions are also cited.

Citations are on https://notendur.hi.is/tpr/software/sres/testfcn.pdf

A.1 Sphere

Sphere function is a convex and unimodal function (cf. Fig. A.1a). Sphere function is defined as follows,

$$f_{\text{Sphere}}(\mathbf{x}) = \sum_{i=1}^{d} x_i^2 \tag{A.1}$$

where $\mathbf{x} \in [-3, 7]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\text{Sphere}}(\mathbf{0}) = 0$.

A.2 Noisy sphere

Noisy sphere function is the sphere function from Appendix A.1 where a Gaussian noise has added to perturb the sphere (cf. Fig. A.1b where $\varepsilon = 0.1$). Noisy sphere function is defined as follows,

$$f_{\mathrm{NoisySphere}}(\mathbf{x}) = f_{\mathrm{Sphere}}(\mathbf{x})\,(1 + \varepsilon\mathcal{N}(0,1)) \tag{A.2}$$

where $\mathbf{x} \in [-3, 7]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\mathrm{NoisySphere}}(\mathbf{0}) = 0$.

A.3 Schwefel

Schwefel is ... (cf. Fig. A.1c). Schwefel function is defined as follows,

$$f_{\mathrm{Schwefel}}(\mathbf{x}) = \sum_{i=1}^{d} \left(\sum_{j=1}^{i} x_j \right)^2 \tag{A.3}$$

where $\mathbf{x} \in [-10, 10]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\mathrm{Schwefel}}(\mathbf{0}) = 0$.

A.4 Ellipsoid

Ellipsoid is ... (cf. Fig. A.1d). Ellipsoid function is defined as follows,

$$f_{\mathrm{Ellipsoid}}(\mathbf{x}) = \sum_{i=1}^{d} \left(100^{\frac{i-1}{d-1}} x_i \right)^2 \tag{A.4}$$

where $\mathbf{x} \in [-3, 7]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\mathrm{Ellipsoid}}(\mathbf{0}) = 0$.

A.5 Rosenbrock

Rosenbrock function is a non-convex function, where the global minimum is inside a long, narrow, parabolic shaped flat valley (cf. Fig. A.1e). To find the valley is trivial. To converge to the global minimum, however, is difficult. Rosenbrock function is defined as follows,

$$f_{\mathrm{Rosenbrock}}(\mathbf{x}) = \sum_{i=1}^{d-1} \left(100 \cdot (x_i^2 - x_{i+1})^2 + (x_i - 1)^2\right) \tag{A.5}$$

where $\mathbf{x} \in [-5, 5]^d$. It has a global minimum at $\mathbf{x} = \mathbf{1}$ where $f_{\text{Rosenbrock}}(\mathbf{1}) = 0$.

A.6 Ackley

Ackley function is a non-convex function, where the function is a fairly difficult problem due to its large search space and its large number of local minima (cf. Fig. A.1f). Ackley function is defined as follows,

$$f_{\text{Ackley}}(\mathbf{x}) = 20 - 20 \cdot \exp\left(-0.2\sqrt{\frac{1}{n}\sum_{i=1}^{d} x_i^2}\right) + e - \exp\left(\frac{1}{2}\sum_{i=1}^{d}\cos(2\pi x_i)\right) \quad \text{(A.6)}$$

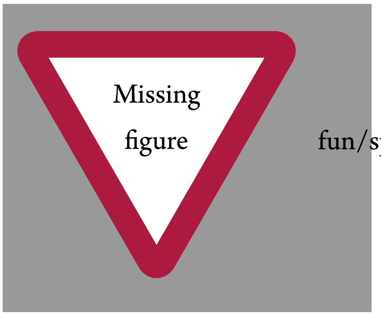
where $\mathbf{x} \in [1, 30]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\text{Ackley}}(\mathbf{0}) = 0$.

A.7 Rastrigin

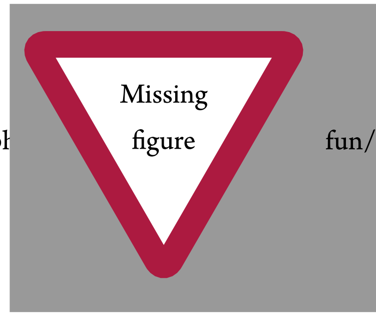
Rastrigin function is based on the sphere function from Appendix A.1 with the addition of cosine modulation in order to produce frequent local minima (cf. Fig. A.1g). Thus, the test function is highly multimodal. However, the location of the minima are regularly distributed. Rastrigin function is defined as follows,

$$f_{\text{Rastrigin}}(\mathbf{x}) = 10n + \sum_{i=1}^{d}\left(x_i^2 - 10\cos(2\pi x_i)\right) \quad \text{(A.7)}$$

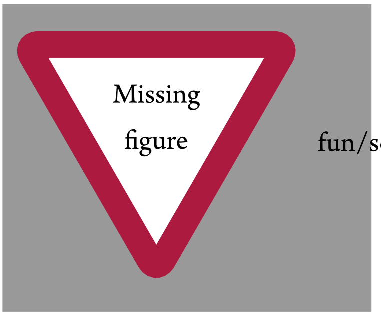
where $\mathbf{x} \in [1, 5]^d$. It has a global minimum at $\mathbf{x} = \mathbf{0}$ where $f_{\text{Rastrigin}}(\mathbf{0}) = 0$.



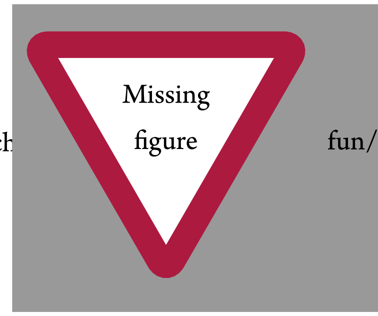
(a) Sphere function



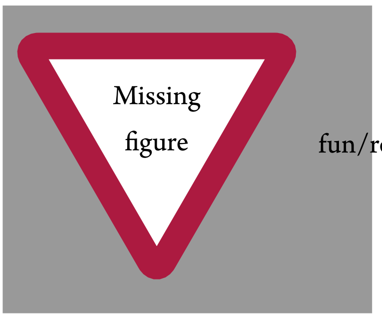
(b) Noisy sphere (with $\varepsilon = 0.1$)



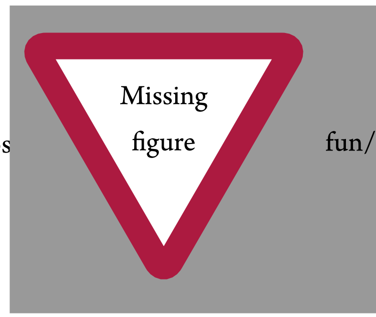
(c) Schwefel



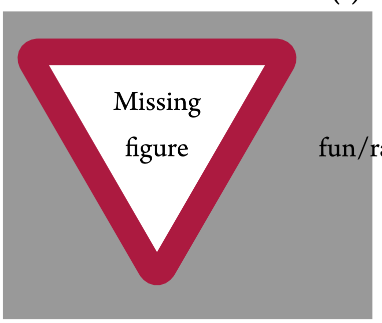
(d) Ellipsoid



(e) Rosenbrock



(f) Ackley



(g) Rastrigin

Figure A.1: Test function suite of two variables in 3D.

PAPERS

But it's no use going back to yesterday, because I was a different person then.

Alice

I

Supervised Learning Linear Priority Dispatch Rules for Job-Shop Scheduling

Helga Ingimundardóttir, Tómas Philip Rúnarsson

School of Engineering and Natural Sciences, University of Iceland, Iceland

Learning and Intelligent Optimization

I

This page is intentionally left blank.

Take care of the sense, and the sounds will take care of themselves.

The Duchess

II

Sampling Strategies in Ordinal Regression for Surrogate Assisted Evolutionary Optimization

Helga Ingimundardóttir, Tómas Philip Rúnarsson

School of Engineering and Natural Sciences, University of Iceland, Iceland

Intelligent Systems Design and Applications (ISDA), 2011 11th International Conference on

II

This page is intentionally left blank.

I wonder if I've been changed in the night? Let me think. Was I the same when I got up this morning? I almost think I can remember feeling a little different. But if I'm not the same, the next question is 'Who in the world am I?' Ah, that's the great puzzle!

Alice

III

III

Determining the Characteristic of Difficult Job Shop Scheduling Instances for a Heuristic Solution Method

Helga Ingimundardóttir, Tómas Philip Rúnarsson

School of Engineering and Natural Sciences, University of Iceland, Iceland

Learning and Intelligent Optimization

This page is intentionally left blank.

It would be so nice if something made sense for a change.

Alice

IV

IV

Evolutionary Learning of Weighted Linear Composite Dispatching Rules for Scheduling

Helga Ingimundardóttir, Tómas Philip Rúnarsson

School of Engineering and Natural Sciences, University of Iceland, Iceland

International Conference on Evolutionary Computation Theory and Applications (ECTA) – Fix margins

You can place todo's for papers in remark

This page is intentionally left blank.

IV

Reeling and Writhing, of course, to begin with, and then the different branches of arithmetic – Ambition, Distraction, Uglification, and Derision.

The Mock Turtle

V

Generating Training Data for Learning Linear Composite Dispatching Rules for Scheduling

Helga Ingimundardóttir, Tómas Philip Rúnarsson

School of Engineering and Natural Sciences, University of Iceland, Iceland

Learning and Intelligent Optimization – Nominated for best paper award

This page is intentionally left blank.

Colophon

This thesis was typeset using LaTeX, originally developed by Leslie Lamport and based on Donald Knuth's TeX. The body text is set in 11 point Arno Pro, designed by Robert Slimbach in the style of book types from the Aldine Press in Venice, and issued by Adobe in 2007. A template, which can be used to format a Ph.D. thesis with this look and feel, has been released under the permissive creative commons share-alike license, and can be found on-line at github.com/tungufoss/hi-thesis.cls or from the author at hei2@hi.is.
Moreover, the epigraphs are from *Alice's Adventures in Wonderland* (1865) and *Through the Looking-Glass, and What Alice Found There* (1871) by Lewis Carroll.