What is a PhD *"Thesis"*

J.N. Oliveira [1]

[1]CCTC, University of Minho, Portugal

MAP-i: Seminar on Thesis Organization and Validation

15th December 2010, Room DI-A1
Braga, Portugal

Preamble

Context: Learning cycles

BSc — 1st cycle: student expected to learn and apply **general**, well-established theories

The "repeat" phase

MSc — 2nd cycle: student expected to learn **specialized** theories and build solutions from them

The "build" phase

PhD — 3rd cycle: student (who thinks she/he can do better than his former teachers) expected to pursue a new **conjecture** (thesis) and provide scientific evidence of it

The "create" ("invent") phase

Mind the terminology

PhD — an academic **degree** (from the Greek $\delta\iota\delta\alpha\kappa\tau\omega\rho\ \phi\iota\lambda o\sigma o\phi\acute{\iota}\alpha\zeta$, Latin *philosophiæ doctor*)

PhD thesis — a scientific **result** (from the Greek $\theta\varepsilon\sigma\iota\zeta$, position)

PhD project — an action, **initiative**

PhD dissertation — a piece of **text**, originally a *discourse* (from the Latin *dissertatio* < *disserere*, discuss)

Doing a PhD — doing “science”, ok?

- PhD projects are a standard way of advancing human knowledge
- The root *philosophiæ* does not mean philosophy as such — it is a sign for **depth of knowledge** or thought
- PhD programmes range over the
  - human (social) sciences
  - natural sciences
  - exact sciences

However, what does **“science”** mean? What tells science apart from other forms of human knowledge?

- PhD students cannot ignore these questions!

Overview of the Scientific Method

Science? Pre-science?

In an excellent book on the history of scientific technology,

> *"How Science Was Born in 300BC and Why It Had to Be Reborn" (Springer, 2003),*

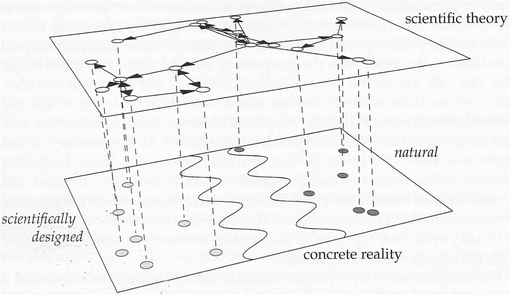
Lucio Russo writes:

> *The immense usefulness of* **exact** *science consists in providing* **models** *of the real world within which there is a guaranteed method for telling false statements from true. (...) Such models, of course, allow one to describe and* **predict** *natural phenomena, by translating them to the theoretical level via* **correspondence rules**, *then solving the "***exercises***" thus obtained and translating the solutions obtained back to the real world.*

Disciplines unable to build themselves around *"exercises"* are regarded as **pre-scientific**.

Scientific engineering ($e = m + c$)

Also from Russo's book :



Vertical lines mean **abstraction**, horizontal ones mean **calculation**:

engineering = model first, then calculate
($e = m + c$)

Example

- **natural phenomena** — planetary motion, objects falling down
- **correspondence rules** — Newton (1642-1727)'s laws of mechanics and gravitation stemming from **model**

$$F = G\frac{mM}{d^2}$$

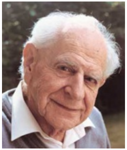
- **"exercises"** — Earth gravitational field,

$$g = \frac{GM}{R^2}$$

then $F = gm$, then $F = m\frac{dv}{dt}i = ma$, then... (you know the rest!)

- **translation back to the real world** — ballistics, space missions, satellite technology, etc

Where does it all begin?



K. Popper (1902-94)

Following the eminent philosopher of science of the 20c Karl Popper (1902-94), science does not arise from **observation** or **inductive** perception of reality only.

Scientific theories, and human knowledge in general, are conjectural or hypothetical, and are generated by **creative imagination**.

This links **science** with **art**.

It means that æsthetic attributes such as **beautiful**, **elegant**, **horrible**, **ugly**, etc apply to science.

Beware: this applies to **PhD** work as well!

Besides imagination, which other skills?

Abstraction! — Quoting Jeff Kramer [1]:

Abstraction *is widely used in other disciplines such as* **art** *and* **music**. *For instance (...) Henri Matisse manages to clearly represent the* **essence** *of his subject, a naked woman, using only simple lines or cutouts. His representation* **removes** *all detail yet* **conveys** *much.*

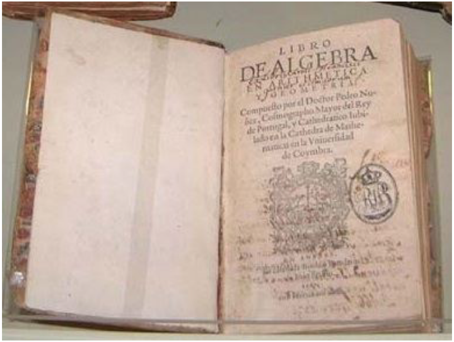
[1] *Is Abstraction the Key to Computing?*, CACM 50:4, pp. 37–42, Apr. 2007.

(Map) abstraction

The famous "abstract map" of London's Underground (1939):

Calculation

The ability to **calculate** with mathematical **models** has marvelled many scientists in the past, notably Pedro Nunes (1502-78):



(...) "De manera, que quien sabe por Algebra, sabe scientificamente".

(...) In this way, who knows by Algebra knows scientifically.

(In *Libro de Algebra en Arithmetica y Geometria* (1567), fol. 270v)

School background on $e = m + c$

The **problem**:

> *Mary's three children were born at a 3 year interval rate. Altogether, they are as old as Mary, who is 48. How old are they?*

The **model**:

$$x + (x + 3) + (x + 6) = 48$$

The **calculation**:

$$\begin{aligned} & 3x + 9 = 48 \\ \Leftrightarrow & \quad \{ \text{ “al-jabr” rule } \} \\ & 3x = 48 - 9 \\ \Leftrightarrow & \quad \{ \text{ “al-hatt” rule } \} \\ & x = 16 - 3 \end{aligned}$$

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The **solution**:

$$\begin{aligned} x &= 13 \\ x + 3 &= 16 \\ x + 6 &= 19 \end{aligned}$$

Conclusion

Everyone with middle school education has followed the scientific method many times, without even noticing it.

Question:

Is it the same in computing?

Computer science — back to 40 years ago

Phrase **software engineering** seems to date from the Garmisch NATO conference in 1968:

> *In late 1967 the Study Group recommended the holding of a working conference on Software Engineering. The phrase 'software engineering' was deliberately chosen as being* ***provocative****, in implying the need for software manufacture to be based on the types of* ***theoretical foundations*** *and practical disciplines, that are traditional in the established branches of engineering.*

Question:

- Provocative or not, how "scientific" do such foundations turn out to be, 40 years later?

Reaction

- The Garmisch NATO conference triggered much research on the so-called *software crisis*.
- In the words of Brian Randell [2], Edsger W. Dijkstra (1920-2002) was *one of a very small number of people who, through their research and teaching, have provided* **computing** *with an* **intellectual foundation** *that can justifiably be termed a* **science**.

[2] Foreword to *Beauty Is Our Business: A Birthday Salute to Edsger W. Dijkstra*, 1990, ISBN-10: 0387972994.

"Beauty is our business"

E.W. Dijkstra (1920-2002)

"...when we recognize the battle against chaos, mess, and unmastered complexity as one of computing science's major callings, we must admit that 'Beauty Is Our Business'".

(E.W. Dijkstra, EWD697)

Still, the questions remain:

- How many have followed Dijkstra's advice?
- Are we doing computer science research in the right way?
- Are we using the right notation, language?
- Does more technology mean better science?
- "Is computer science science?" (Denning, 2005)

Complexity, Complication, Obfuscation

- **Complexity** — property of being intricate but with formalizable structure
- **Complication** — messy, lacking structure
- **Obfuscation** — formalization intended for bewilderment rather than enlightening (worst of all)

By definition, a PhD project is close to some **frontier of knowledge**. Therefore:

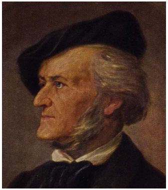
- Don't expect an easy task
- It will be **complex** — so, don't **complicate** it further.
- Never dare going into obfuscation!

Still Complexity versus Complication

Compare with Daniel Barenboim's appreciation of Richard Wagner's music [3]:

D. Barenboim (1942-)

- It's **complex**, but not complicated
- being complex means that it is a structure of many, smaller parts
- Such parts are **simple**
- Would it be complicated, it would have no structure and little contents.



R. Wagner (1813-1883)

[3] In *Daniel Barenboïm dirige la Walkyrie à la Scala de Milan*, Mezzo channel, quoted from memory.

Planning a PhD dissertation

Questions

- **How** should I structure it?
- When should I start?
- What should I write?

Natural questions, aligned with the so-called **Aristotelian categories**:

> *Wherever your are, whatever you do, your ideas, concepts, "things" etc. are multidimensional in nature:*
>
> What *the thing is about*
> What for *the purpose of the thing*
> Why *bother with the thing*
> When *did the thing happen?*
> Where *is the thing taking place?*
> How *is/was the thing carried out?*

What is it?

Recall that:

- A PhD dissertation is a **document** which should provide scientific evidence of some **novel** result(s) in some area of knowledge
- Following the scientific method, the concepts involved in such results should be **formalized** first (vertical arrows in Russo's diagram) and then **reasoned** about (horizontal arrows in the same diagram),

This entails some structure in the text:

- **Definitions** for each correspondence rule (in Russo's sense)
- **Theorems** for each "exercise" (in Russo's sense)

What about the overall text?

How should I structure it?

Recall the typical structure of a mathematical argument, made of results in the form of theorems, each involving:

1. Thesis (T)
2. Hypothesis (H)
3. Proof ($H \Rightarrow T$)
4. Corollaries
5. Lemmas
6. Others' theorems

How should I structure it?

Since the purpose of a PhD dissertation is that of providing scientific evidences, its **overall structure** should mirror the shape of a mathematical argument. Here it goes:

Maths	**PhD** (parallel)	**Dissertation**
Thesis (T)	Main result	Contribution chapter
Hypothesis (H)	Context	State of the art [4]
Proof ($H \Rightarrow T$)	Evidence	Central chapters
Corollaries	Application	Case studies
Lemmas	Support results	Appendices
Others' theorems	Evidence elsewhere	Bibliography

So, in a sense, writing up your dissertation means *proving your "theorem"*.

[4] Inc. previous work.

How should I structure it?

Therefore, it's no wonder that a PhD thesis should be structured as follows [5]:

- Introductory material:

  1st Chapter — Context, motivation, main aims
  2nd Chapter — State of the art review; related work
  3rd Chapter — The problem and its challenges

- Core of the dissertation:

  4th Chapter — Main result(s) and their scientific evidence
  5th Chapter — Application of main result (examples and case studies)
  6th Chapter — Conclusions and future work

[5] Number of chapters not strict: may vary according to the needs.

How should I structure it?

- Auxiliary material:

  Bibliography — List of works referred to in the main text

  Appendix A — Support work (auxiliary results which are not main-stream)

  Appendix B — Proofs of some results (lengthy, technical proofs which would compromise readability of main text)

  Appendix C — Listings (should this be the case)

  Appendix D — Tooling (should this be the case)

This should be complemented by some extra matter, as in the following slide.

How should I structure it?

1. Front matter:

   Title page — of course!

   Abstract page — summary of the work

   Acknowledgements — thanks to tutors, colleagues, institutions (funding), etc

   Glossary — list of acronyms and their meaning

   Lists — of tables, of figures etc (automatically generated if using a proper authoring system)

2. Rear matter:

   Index of terms — index of mentioned entities, with references to where (page numbers) they are mentioned in the text.

Writing up

When should I write it?

- You should start writing up your thesis on the **very first day** you start your project
- Of course, this assumes you've understood your project theme sufficiently well
- On that day only a **sketch** of the dissertation can be written — but already containing the standard chapters.
- Use this skeleton as a **road map** and **diary** — you can always keep auxiliary information in the form of comments.
- You may even add **time stamps** to it (these will tell you how fast you've done your work — useful in measuring effort)

Whom should I write it for?

- To everybody — I mean:
- Introductory and conclusive matter should be written in a style easy to understand by non-specialists
- Core chapters will inevitably be technical, so they are bound to be written for the specialist.

However:

- Avoid colloquialisms and any form of majestic style (be modest)

Wanting to check whether you've mastered your domain of knowledge upon completion of your PhD?

- you should be able to explain what you did to anyone you may meet in the street.

How do I write it?

- Use a proper **text authoring system**
- By **proper** I mean one that:
  - Handles references and maintains **referential integrity**
  - Automates **routine tasks** such as numbering, bibliography, generation of lists and indices
  - Integrates well with other tools
- One such system is the Knuth-Lamport's LaTeX's text preparation system (Goossens et al., 1997)
- (Maybe you know of others).

How do I write it?

Handling references:

- Concepts, entities etc have a **name** (reference) and often a type
- Textual information contains (implicitly) a set of **name spaces**
- A name in each name space identifies a unique object — it is a **reference**
- Name spaces call for **referential integrity**
- Some of this is ensured by the text authoring system itself — eg. names of figures, tables, sections, theorems, etc
- One should be very careful about handling other names.

How do I write it?

For those not handled, here is how I like dealing with them (for LaTeX users only — sorry!): for each entity, eg.

- Entity: University of Minho
- Acronym: UM

define (under package `hyperref`) its reference name:

```
\newcommand{\uminho}[1]{
     \href{http://www.uminho.pt}{#1}
     \index{UM!University of Minho}}
```

Every time you write eg. `\uminho{the university}`,

- You include a link to the website of the mentioned entity
- An entry is added to the index of terms, meaning that the occurrence of term `uminho` in the **current page** is recorded.

How do I write it?

Then an acronym (short-cut) can be defined:

```
\newcommand{\UM}{\uminho{\textsc{u.m.}}}
```

So, everytime you use acronym `\UM`, LaTeX typesets U.M. and does the same as above concerning hyperlinking and index-management.

This saves you from referring to entities which are not in the list of terms

Last but not least:

- Keep your dissertation in a document version-control system like eg. CVS or DARCS — among many other (good) alternatives, many web-based.

Interfacing with others' work

That is, bibliography management:

- Nobody doing relevant research is alone
- Research is actually a social activity, with permanent interaction in the form of meetings, talks, and so on
- Giving credit to the others's contributions is the main rule of the game
- With the information resources of today, managing this may be hard (too much data!) without a proper infra-structure.
- This may take the form of a **bibliography** database.

Interfacing with others' work

- Systems around BibTEX provide very easy management of bibliography data
- A bibtex record is like a database record, eg:

```
@book{GRM97
   , title     = {The LaTeX Graphics Companion}
   , author    = {Michel Goossens and
                  Sebastian Rahtz and Frank Mittelbach}
   , publisher = {Addison-Wesley}
   , year      = {1997}
   , note      = {ISBN 0-201-85469-4}
}
```

- You may add your own attributes (which don't get printed) like the ID of this book in your own library, bibliometric stuff, and so son.

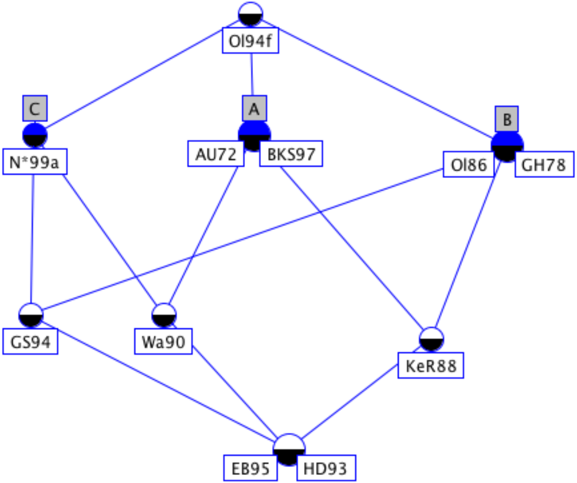
Interfacing with others' work

Classifying your bibliography:

- In particular, you may add a BibTEX attribute named `keywords` to each record of interest
- This will **classify** your records according to keywords relevant to your research
- You many even use the technique of **formal concept analysis** (FCA) developed by Ganter and Wille (1999) to structure your data in a **lattice** of concepts
- Some FCA systems (such as ConExp) offer you a user interface to manage and display your concept lattice (next slide)

Interfacing with others' work

Example concept lattice (11 records, three attributes A, B abd C):



Interfacing with others' work

The classification which generates such a lattice is as follows:

Ref	A	B	C
Ol94f	0	0	0
AU72	1	0	0
Ol86	0	1	0
N*99a	0	0	1
KeR88	1	1	0
GS94	0	1	1
Wa90	1	0	1
EB95	1	1	1
BKS97	1	0	0
GH78	0	1	0
HD93	1	1	1

Such concepts should help in organizing your review of the state of the art.

Some links

- *How to Write a PhD Thesis* — www.phys.unsw.edu.au/~ jw/thesis.html
- *Writing and Presenting Your Thesis or Dissertation* — www.learnerassociates.net/dissthes/
- *BibSonomy* (a system for sharing bookmarks and lists of literature) — www.bibsonomy.org
- *Small guide to making nice tables* — www.inf.ethz.ch/personal/markusp/teaching/guides/guide-tables.pdf
- *DBLP Computer Science Bibliography* (comprehensive generation of BibTEXrecords) — www.informatik.uni-trier.de/~ ley/db/index.html

among many others Google will offer to you.

Final suggestions

- **Interact** with other researchers in your field
- Once you have something to show, build a **research blog**
- Try and **publish** your work in good conferences — the best way to validate your contributions
- Good **papers** convert to good chapters in the dissertation
- Offer your **services** in OC/PCs of **conferences** in your area

and don't forget

- to be **creative** (recall K. Popper)
- to have **fun** (if you don't get excited with your project who will?)

References

Peter J. Denning. Is computer science science? *Commun. ACM*, 48(4):27–31, 2005.

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Michel Goossens, Sebastian Rahtz, and Frank Mittelbach. *The LaTeX Graphics Companion*. Addison-Wesley, 1997. ISBN 0-201-85469-4.

L. Russo. *The Forgotten Revolution: How Science Was Born in 300BC and Why It Had to Be Reborn*. Springer-Verlag, September 2003. URL http://www.springer.com/978-3-540-20396-4.