MSc Projects (MATH61000)

Omar León Sánchez and Marcus Tressl

Course homepage
(including these slides)

MSc Pure Mathematics and Mathematical Logic

The University of Manchester, Department of Mathematics

1. Content of this module - overview

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4. All material that we provide for this module (including these slides) are posted on the module's homepage. There is nothing on "Canvas" or "My Manchester".

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Part A: Mathematical writing, presentation and mini-project

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Part A: Mathematical writing, presentation and mini-project

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- Students write a mini-project over a period of 6 weeks. Submission is on Canvas, submission deadline: 3pm on Friday of week 7.

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A detailed timetable may be found at the module's homepage.

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  Please choose at least two supervisors with topics from ProjectsMATH61000.pdf and send your choices via email to Omar León Sánchez (omar.sanchez@manchester.ac.uk). Please indicate your preference (or say that you have no preference); we try to accommodate everybody's choice. You may contact prospective supervisors to get further information about the advertised project.

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- The mini-project and the main project do not need to be connected, you can use the mini-project also to close some gaps that you see from your UG studies. However, if you want to get some inspiration for the mini-project from the available main projects, have a look at ProjectsMATH61000.pdf. An example of a main project may be found in MainProjectExample.pdf.

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     Feel free to use the corresponding LaTeX-file MiniProjectExample.tex used to produce this example as well as the file MiniProjectExample.bib holding the bibliographic resources.

     You do not need to use these files, however you are required to use the page layout used in these files. More about this may be found here.

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2. MathScinet: `https://mathscinet-ams-org.manchester.idm.oclc.org/mathscinet/search.html` (Needs your University credentials.)
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   - It has reviews of the items which is sometimes telling in an understandable way what is in a particular text.
   - You can search the full text of these reviews (and title / authors).
   - The items are linked, i.e. you can search who has quoted a particular book or article, which can be very helpful to find the correct resource.

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5. Read references of nearby topics. For example if you choose to write about a specific topic in Analysis, grab a big standard work on Analysis and look through the references. Or find a research article about the specific topic and check their references for general books about your topic.

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6. Find a good book that uses your topic, but is not mainly about your topic. For example: There are plenty of books about category theory, but these are for most purposes too massive to get a quick introduction to the fundamental part of the theory. Now, the book "Algebra" by Serge Lang uses category theory to some extent and has a short and concise appendix on category theory focussing on the essentials.

3. Resources for mathematics - Preprints and unpublished notes

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These sources are in principle trustworthy, but have not been refereed or reviewed. So care has to be taken. For notes of lectures, make sure the source is genuine. For example, suppose you find this source. It is not available on any website, but still the bots find it. Would you trust it?

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- Wikipedia has a large range of mathematical topics, definitions and explanations. You can start reading about some topic there if you cannot find a book right away. However, care has to be taken, frequently the material on Wikipedia is outright wrong. Still, you might get an impression on what a certain notion is about or to which part of mathematics it belongs to. Further, even if the text is wrong, the page might give you references for further search, or keywords that you can use for further search.

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- MathOverflow and Stackexchange are forums where people are asking and answering mathematical questions (there are many others of course but these two are to some extent moderated, i.e. they do not contain arbitrary nonsense). Users frequently post links to trusted references, so this is of use.

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There are two reason for finding resources:

- Find statements, proofs and explanations that you will reproduce and elaborate on.
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  Important: References need to be available to the reader and stable (contents of websites are normally unstable, here is an exception).

4. Topics for the mini-project I

Below is a list of suggestions for mini-project topics. You can work on exactly the topic as named, or you can use the information under the Wikipedia link as an entrance point to find a related topic.

If you want to work on a topic that is not listed, you are welcome to do so. In any case we will discuss your choice in the individual meeting in week 1. The purpose of this meeting is to make sure your topic is doable in 6 weeks.

The topics are of varying difficulty and volume with respect to prerequisites. Note that the focus in the mini-project is more on the presentation side rather than on the mathematical side.

4. Topics for the mini-project II

Be careful: A seemingly easier topic might be harder to write on, because you need to write about a broader context and make a wise selection of material. A harder topic is mathematically more challenging but easier to organise.

For example, consider the two topics "Introduction to Modules" and "Modules over Principal Ideal Domains".

Obviously the second one will need knowledge of the first one. Now in the second topic one can treat the introductory material very briefly in a preliminary section or even just treat it with references. Then the project would essentially elaborate on the main theorem about modules over principal ideal domains. On the other hand "Introduction to Modules" requires a clever choice of selection (a full introduction would contain hundreds of pages) and organisation of material.

4. Topics for the mini-project III

The topics:

A. Algebra
   1. Noetherian rings and Hilbert's basis theorem. Wikipedia
   2. Cayley-Hamilton for rings and applications (e.g. Nakayama's lemma). Wikipedia
   3. Algebraic and integral elements. Wikipedia
   4. Introduction to modules. Wikipedia
   5. Modules over principal ideal domains. Wikipedia
   6. The p-adic numbers. Wikipedia
   7. Absolute values on $\mathbb{Q}$. Wikipedia
   8. The algebraic closure of a field. Wikipedia
   9. Introduction to categories and functors. Wikipedia

B. Metric spaces and topology
   1. Introduction to topology. Wikipedia
   2. Alexander's subbase lemma. Wikipedia
   3. Tychonoff's theorem. Wikipedia
   4. The contraction mapping principle and applications. Wikipedia
   5. Banach Fixed Point Theorem, the general statement. Wikipedia
   6. Urysohn's lemma. Wikipedia
   7. Partition of unity. Wikipedia

4. Topics for the mini-project IV

C. Analysis

1. Constructions of the field of real numbers. Wikipedia
2. The implicit function theorem. Wikipedia
3. Power series, formal and convergent. Wikipedia
4. Hadamard's Lemma and its applications. Wikipedia
5. The Stone-Weierstraß Theorem. Wikipedia
6. Picard-Lindelöf: The fundamental theorem of ordinary differential equations. Wikipedia
7. Introduction to Banach spaces. Wikipedia
8. Transcendence of the Euler number. Wikipedia
9. Introduction to measures. Wikipedia

D. Geometry

1. Incidence geometry. Wikipedia
2. Introduction to manifolds. Wikipedia
3. Helly's theorem with applications. Wikipedia
4. Carathéodory's theorem on the computation of the convex hull and its generalizations. Wikipedia

4. Topics for the mini-project V

E. Combinatorics
   1. Ramsey's theorem and its applications to combinatorics and number theory. Wikipedia
   2. Spanning trees. Wikipedia
   3. Semilattices. Wikipedia
   4. The Schröder-Bernstein Theorem and cardinal numbers. Wikipedia

F. Mathematical Logic
   1. The Lemma of Zorn and its applications. Wikipedia
   2. Introduction to Modal Logic. Wikipedia
   3. The Soundness and the Completeness Theorem. Wikipedia
   4. Ultraproducts and Łoś's theorem. Wikipedia

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2. The mini-project is marked according to the Mini-Project Rubric. The main-project is marked according to the Main-Project Rubric.
3. In the mini-project, 80% of the marks will be allocated to the submitted paper and 20% of the marks will be allocated to an oral presentation about the mini-project in week 8 of semester 1.

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   Apart from the weighting of the oral, there is another major difference in the marking of the two projects: The mini-project has its main weight on presentation, whereas the main-project has its weight on mathematical content.

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5. The marking will follow the University's position on the use of AI.

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1. The **LaTeX program** itself.
   We recommend MikTeX. This works equally well under Windows, Linux/Ubuntu and Mac. Installation is very easy, instructions can be found on the program's website.
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There are many good LaTeX-editors (and one major other LaTeX distribution, called TeXLive, or MacTeX for the Mac) available. The choice above seems to us the simplest one to get started. (Note that not every good editor has explicit support for LaTeX.) Let us know if you cannot get these to work.

You are also welcome to use Overleaf, which is in particular well suited for editing files by several authors, but has various restrictions compared to the setup above, when working as a single author.

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There are many resources on the web to learn LaTeX, here are a few:

- LaTeX homepage,
- LaTeX Wiki book
- Paul Johnson's LaTeX site
- TeX FAQ
- CTAN: Contains (almost) all available packages.
- Find (almost) any symbol in the Comprehensive LaTeX Symbol List
- A rich source of examples of diagrams and pictures, including code, may be found at `http://www.texample.net/tikz/examples/`

Most LaTeX editors will also assist you finding LaTeX-documentation and will suggest various standard templates for writing the most common pieces of mathematics (like lists, theorem and proof environments, displayed formulas, matrices, diagrams).

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- The mini-project is supposed to be between 12 and 16 pages (including cover sheet, references and index). Hence the mathematical text (including the introduction) should be between 10 and 14 pages. Can you write about your selected topic in 10-14 pages?

  Also recall that there are layout requirements.

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- How much of the topic is new to you? From the 60 hours allocated for the mini-project, you shouldn't spend too much time in learning new material. If you have never written a project and you have no experience with writing LaTeX, I recommend choosing a topic that you know more or less already, or you can fill the missing details in 10 hours. If you have already written some mathematical text using LaTeX you might want to allocate at least 20 hours for the actual writing, a safer option would be 30 hours.

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- You will have to present the material in week 8 to the lecturer. Can you see yourself talking about the topic? (In week 2 there will be a lecture on presenting mathematics.)

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- You will have to present the material in week 8 to the lecturer. Can you see yourself talking about the topic? (In week 2 there will be a lecture on presenting mathematics.)
- Can you find a good variation of trusted resources from which you can choose? It is not a good idea to just have a single source as you need to produce your own account of the topic.

7. How to find a suitable topic?

- You will need to say *something* in the mini-project. Which idea will you communicate?

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- Whom will you be writing for? Is the text to be understandable for a year 1 UG mathematics student? A year 3 UG mathematics student? You will need to write about what a reader is supposed to know to read your project.

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There are various books about how to write mathematics. There is no one way, but there are some guiding principles. More on this next week. For now, maybe read the preface of [Viv14].

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Required layout of the project files (use these for the mini-project and for the main-project):

Font: Use the default font provided automatically, but set it to 12pt.

Text height: 630pt

Text width: 460pt

Line spread factor: 1.3

If you use MiniProjectExample.tex (together with MiniProjectExample.bib, holding the bibliographic information), this layout is already set for you. Otherwise you need to consult the LaTeX-documentation on how to set this layout.

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A summary of how to write mathematics that I very much agree with is given by Paul Halmos in [Hal70, p. 124, last paragraph of section 1]:

> *"The basic problem in writing mathematics is the same as in writing biology, writing a novel, or writing directions for assembling a harpsichord: the problem is to communicate an idea. To do so, and to do it clearly, you must have something to say, and you must have someone to say it to, you must organize what you want to say, and you must arrange it in the order you want it said in, you must write it, rewrite it, and re-rewrite it several times, and you must be willing to think hard about and work hard on mechanical details such as diction, notation, and punctuation. That's all there is to do."*

8. Global strategies for writing

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2. You must have somebody to say it to. Who is your audience? This is very important because it will give you a separation of the material that you will elaborate on and the material that will be in the prerequisite section (or will just be quoted). It will also help you make a decision on what to justify and what to deem as "known".

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3. When the first two points have an (approximate) answer: make a rough plan how to organise the material. Do you want to write about exciting applications of your main theorem or theme? How much additional theory, formalism or explanations will these applications need to address the target audience?

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   It does not need to be the first section and it should not be the introduction (the introduction is written at the very end). For example you could try to write up one of the main theorems that you want to communicate, including a (sketch of a) proof. While doing so, you will see material that has to be included, objects that have to be defined and other explanations that need to be present. This gives some information about the organisation of material.

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5. Write sections in spirals: 1,2,1,2,3,1,2,3,4,. . . and re-organise if necessary. Look at earlier sections in the light of new material that has been added. Ask yourself if the original organisation needs amendment. (Normally the answer is: yes).

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6. A common problem in writing mathematics is that at the beginning you do not foresee all the technical material that you have to include, which forces a rearrangement of the original plan.

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There are various books about how to write mathematics. There is no one way, but there are plenty of guidelines available, for example see [Gil87; Hal70; Knu89; Kra97; Ros06; Viv14].

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4. Create subsections if this helps to organize the material.

9. Writing principles - numbering and notions

5. Numerate statements for easy referencing and number them sensibly. For example, if you have an item numbered by "3.2", there should not be another item with the same number: Hence, if you have no subsections in section 3 say, all facts in section 3 should have two digits. However, if you have subsections in section 3, all facts in section 3 and its subsections should have three digits (see the mini-project example for implementation using the command \numberwithin).

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6. When you introduce a new notion, make sure the reader can find this easily later on. Traditionally you will create a "Definition", but sometimes new notions are introduced within facts or in a free floating text. When you use the notion later on, help the reader finding the definition easily. The easiest way is to **boldface new notions**, wherever they are defined. An index is obviously also very helpful and very easy to do, see the mini-project example for implementation.

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7. Many mistakes in projects come from ill-defined objects. Make sure that all objects that you are introducing are well-defined.

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10. Use of general conventions. If you are working under some specific assumption, e.g. "all rings are commutative", repeat all these conventions at the beginning of each sections. If you have plenty conventions, you can say "the conventions of the previous section remain in force". Conventions that are used throughout the text should be stated at the end of the introduction.
11. Think carefully about which facts you want to label as Theorem, Proposition, Lemma, Remark, Observation etc.
12. Frequently, technical material is gathered in lemmas. Say before these lemmas where they will be used.

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When you proof read, you could improve this to

> *Let C be a perfect and nowhere dense subset of X.*

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- Simple declarative sentences are the best for communicating definitions and facts. For example,

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- Display important or complex formulas. See 2.2.6(ii) and (iii) of the mini project for examples (find the code in the LaTeX-file).

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- Do not start sentences with mathematical symbols and do not let symbols clash at punctation. For example

  "This shows that $x \in G$. $x \in H$, because..."

  is unreadable. Instead write

  "This shows that $x \in G$. Furthermore $x \in H$, because..."

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- Resist symbols that are not used in statements, like "Every differentiable function f is continuous." What does f contribute here?

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  You may also use AI to double check your spelling, but you then need to double check the result and make sure that the content of the sentence is not changed.

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2. An example might show how a specific fact is useful in a concrete context that is known to the reader. For example, the intermediate value theorem could be followed by an example showing how the theorem establishes solvability of the equation $\cos(x) = x$ in $\mathbb{R}$.

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2. An example might show how a specific fact is useful in a concrete context that is known to the reader. For example, the intermediate value theorem could be followed by an example showing how the theorem establishes solvability of the equation $\cos(x) = x$ in $\mathbb{R}$.
3. A counterexample might show that perceived improvements of facts do not hold. (E.g.: After the theorem saying that differentiable functions are continuous, there could be an example showing that the derivative is not necessarily continuous).

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1. A (counter-)example could explain why certain assumptions in facts are necessary. For example, the boundedness theorem (saying that every continuous function, defined on a closed and bounded interval, attains a global maximum) could be followed by two examples showing that both assumptions "closed" and "bounded" are necessary for the conclusion of the theorem. (Do not write: "The theorem fails without these assumptions", because a theorem cannot fail. Only the *conclusion* of the theorem might fail.)

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2. Do not write trivial examples without a good reason. If you define what is a topology or a Boolean algebra and then your only example is "$\{\emptyset, \mathbb{R}\}$", why would you state this? One reason could be: It is the smallest topology on $\mathbb{R}$ and this might be of interest for systematic reasons. However it does not elude the definition of topology and a more serious example should be presented.

11. The role of examples

1. Avoid writing overly complicated examples or endless example calculations, unless this serves some purpose - in that case: name the purpose.
2. If appropriate you can also include a picture or a diagram. Use "TikZ" to implement this (it is a package that is already loaded in the mini-project example). See `http://www.texample.net/tikz/examples/` for plenty of ready made examples including LaTeX-code, which you can copy into your LaTeX-file and then tilt according to your needs.

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6. If you do a proof by contradiction: tell this to the reader in some form.
7. If you do a proof by induction, say what you are inducting on.

13. Referencing and citations - general rules

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- You can give references for several facts that you are writing about at the beginning of the corresponding section. For example by saying "The material in this section comes from Reference 1 and Reference 2".

13. Referencing and citations - implementation

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- Avoid using references to websites without any other supporting evidence. If you have to quote a website, include full page title, full URL and a date when you have visited the website. For example "Prime numbers, `www.wikipedia.org`" is not appropriate. Instead write "Prime number, `www.wikipedia.org/wiki/Primes`, retrieved on 15/9/2018".

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- Find bib-files on `https://mathscinet-ams-org.manchester.idm.oclc.org/mathscinet/search.html` as follows: Search for an item; if the website gives you a list of entries, open the one that you are looking for; then click on 'Select alternative format' and choose 'BibTex'. Then you can copy and paste the displayed information into your bib-file.
  There are also bib-files on arXiv if you are working with preprints.

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- In order to quote an item that is listed in the bib-file, use the \cite - command together with a shortcut to the entry of the bib-file. For a concrete example look at the purple reference [Sto36] at the beginning of the introduction of the pdf file of the mini-project example. This is produced with the command \cite{Stone1936} in the tex-file of the mini-project example. The label "Stone1936" refers to the name of the corresponding entry in the bib-file of the mini-project example. The actual output, namely [Sto36], is created by the bibtex program.

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- You can also add entries to the bib-file yourself by using the appropriate format, which may be found here.

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This is written at the end, when you know exactly what is in your text. In the first place, you should ask yourself the following questions: Which purpose is served by the introduction? When you read books or papers, what do **you** expect from their introduction and what do you get?

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- You could write about the motivation for the project.
- Who is addressed by the project, what is its intended audience, what is the reader assumed to know?
- At the end of the introduction, normally a brief overview of the project is given, e.g. by making a rundown section by section.

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- If you want to include something about the history of the subject or about mathematicians, you must include a trusted reference where this can be verified.
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- **Hint:** Read introductions of papers. In trusted resources you often find well written introductions. Try to extract some principles that are used in these introductions. On arXiv you might find some less favorable examples.

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- Which facts are you using and where can the reader find these in the literature.

16. The Presentation

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Here are some hints and strategies for presentations of mathematics using a board (black or white). A presentation using slides

- could be harder to follow for the audience,
- could be less entertaining for the audience,
- connects less with the audience than a talk on the board, where the audience sees the presenter working, and
- could take much longer to prepare.

So we will focus on presentations using a board for the moment, but many of the things said below apply to both ways.

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- Try to develop a central idea. Avoid putting the main idea at the very end, in fact name the concrete goal of your talk as soon as the terminology has been clarified.
  If you run out of time, the talk will either not reach the idea or you have to rush through material. It is better to plan for certain material that can be omitted. You could put weights on the material. Label those things that are absolutely necessary for the talk and those that are omittable (but still all this material should originally fit into the allocated time).

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- Include time for interruptions. These could be: questions from the audience; you are making mistakes/typos.

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- Look at the room a couple of days before the talk, so you know how much space you have on the board.

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- A second common issue with slide presentations is the dissonance of what is on the slides and what the speaker is saying. The audience tends to read what is shown to them. If the presenter is talking about something else, this is often overheard.
- A characteristically bad talk makes both these mistakes. The audience sees slides, tries to read them, but is not given enough time to do so - while the presenter is talking about something that is actually not on the slides.

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  2. For mathematical formulas: Write out the slide, this is the minimum time of how long the slide should be shown to the audience.
- If you follow this strategy, please be strict. There is obviously a trap here: One is tempted to put more on the slides to "just show the audience this or that". Then the bad part of the presentation starts.

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From the website you can also get a very detailed documentation and the code of a running example. Copy this example to an empty file, this file then should compile right away.

16. The Presentation - assessment criteria

The talk will be assessed by us using the following criteria:

- Is the mathematics correct?
- Is a context given and is a central goal communicated?
- Are all objects that are necessary for understanding the contents, properly defined/explained? This of course depends on the intended audience (so a word about that at the beginning should be said).
- Is the presentation balanced and is the material presented efficiently (inefficient/unbalanced might for example be: spending much time on something obvious and then quickly going through something difficult)
- Is the speaker talking to the audience?
- Is the handwriting legible (if you do slides: is there enough time for the audience to actually read the slides and to listen to the speaker)
- How does the speaker respond to questions?

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