Databases of problems using LaTeX

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1 Overview

This document describes the package `problems`. This package allows the management of a database of problems (with optional solutions) within LaTeX. For example the code

```
\problems{2-1}
```

produces the output

1. The one dimensional (linear) wave equation is given by

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2} \tag{1}$$

where c is the (constant) wave speed. Show that this equation may be rewritten as the coupled system of two first order equations

$$u_t - c\,u_x = w$$
$$w_t + c\,w_x = 0.$$

Hence show that the general solution of (1) is

$$u(x,\ t) = F(x - ct) + G(x + ct)$$

for arbitrary functions F and G.

Of course it is not magic. We first need to create a database of problems. Loading

```
\usepackage{problems}
```

will then allow us the access this database to produce tutorial, assignments or examination papers. However with the `solution` option specified

```
\usepackage[solution]{problems}
```

the output becomes

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for arbitrary functions F and G.

SOLUTION:
Let $w = u_t - cu_x$. Then

$$w_t + cw_x = (u_t - cu_x)_t + c(u_t - cu_x)_x = u_{tt} - c^2\,u_{xx} = 0.$$

Solving $w_t + cw_x = 0$ by the method of characteristics, gives $w(x,\ t) = P(x - ct)$ for some arbitrary function P. Thus

$$u_t - c\,u_x = P(x - ct).$$

The characteristic variables for this equation are $t = \tau$ and $x = \xi - c\tau$. In characteristic variables, the equation is

$$U_\tau = P(\xi - c\tau - c\tau) = P(\xi - 2c\tau)$$

and so

$$U = F(\xi) + G(\xi - 2c\tau)$$

where $G' = -\frac{P}{2c}$ (an arbitrary function!). Finally we obtain

$$u(x,\ t) = F(x + ct) + G(x + ct - 2ct) = F(x + ct) + G(x - ct)$$

as required.

2 THE DATABASE

The database file is a flat ASCII file. This can be maintained using any text editor or a specialized BIBTEX manager tool like JABREF. Its format is straightforward. The database entry for the above example is

```
@QUESTION{2-1,
  problem = {The one dimensional (linear) wave equation is given by
        $$ \pder[2]{u}{t^2} = c^2 \, \pder[2]{u}{x^2} \label{wave} $$
        where $c$ is the (constant) wave speed. Show that this equation
        may be rewritten as the coupled system of two first order equations
        \begin{align*}
        u_t - c \, u_x &= w \\ w_t + c \, w_x &= 0.
        \end{align*}
        Hence show that the general solution of (\ref{wave}) is
        \[ u(x, \ t) = F(x-ct) + G(x+ct) \]
        for arbitrary functions $F$ and $G$.},
  solution = {Let $w=u_t-cu_x$. Then
        \[ w_t+cw_x = (u _t-cu_x)_t + c(u_t-cu_x)_x
        = u_{tt}-c^2\,u_{xx} = 0. \] Solving $w_t+cw_x=0 $ by the method
        of characteristics, gives $w(x, \ t) = P(x-ct)$ for some arbitrary
        function $P$. Thus \[ u_t - c \, u_x = P(x-ct). \] The characteristic
        variables for this equation are $t=\tau$ and $x = \xi -c \tau$. In
        characteristic variables, the equation is
        \[ U_\tau = P(\xi-c\tau-c\tau) = P(\xi-2c\tau) \] and so
        \[ U = F(\xi) + G(\xi-2c\tau) \] where
        $G'=-\frac{P}{2c}$ (an arbitrary function!). Finally we obtain
        \[ u(x, \ t) = F(x+ct) +G(x+ct-2ct) = F(x+ct) + G(x-ct) \]
        as required.},
  keywords = {tutorial, characteristics},
  owner = {msh51},
  timestamp = {2009.03.02}
}
```

The first entry is the BibTeX key. This is the (unique) key that refers to the question. The remaining keys can occur in any order. The keys are

`problem`	LaTeX fragment for the problem.
`solution`	LaTeX fragment for the solution.
`keywords`	Searchable index.
`comment`	A free field that can be used, for example, to give a textbook reference.
`owner`	Usercode of who wrote the question.
`timestamp`	Time at which the entry was added to the database

All these keys are optional (though it would make no sense to have the `problem` key undefined). With a BibTeX manager like JabRef the `owner` and `timestamp` keys are automatically entered into the database. The LaTeX fragment may be simply a reference to a scanned document. For example

```
  solution = {\insertpdf{Q1-32-up}},
```

will insert the file `Q1-32-up.pdf` for the solution. `\insertpdf` is simply a called to `\includegraphics` (with the scale factor set to 0.9). It accepts all the options of `\includegraphics`. For LaTeX users (as distinct from pdfLaTeX users), scanned files need to be eps files and a direct call to `\includegraphics` is required.

Text can be placed in the problem but which is not included in the solution by

```
\NotinSolution{This will not be printed when solution option is chosen.}
```

A marking scheme can be included in the `solution` field by

```
\Marks[Lose 1 mark if the case $n=0$ is not considered]{3}
```

This will only be printed when the `marks` option is given (see below).

Verbatim Text

If the LaTeX fragment includes verbatim text (for example, Maple or Matlab code) then it should be read in from an external file (a similar approach is taken by the beamer class with its fragile construction). The simplest way to do this is to use the `fancyvrb` package. With this package loaded, the command

```
\VerbatimInput[formatcom=\color{red},xleftmargin=0.06\textwidth,numbers=left]
                      {4-6.mpl}
```

gives the code indented, numbered and printed in red

```
1  phi:=x->piecewise(x<Pi/2,x,Pi-x):
2  psi:=x->0:
3  d:=n->2*int(phi(x)*sin(n*x),x=0..Pi)/Pi;
4  simplify(d(n));
5  simplify([d(2*n),d(2*n+1)]);
6  u:=N->(x,t)->sum(d(n)*cos(n*t)*sin(n*x),n=1..N):
7  soln:=u(4):
8  soln(x,t);
9  plot3d(soln(x,t),x=0..Pi,t=0..10,axes=boxed,style=patchcontour);
10 plot({phi(x),seq(soln(x,t),t={0,2,4,10})},x=0..Pi);
```

One advantage of this approach is that the *same* file `4-6.mpl` can also be used in Maple.

3 The Output

The problems in the database are accessed by loading the package

```
\usepackage{problems}
```

This package has a number of options.

`solution`	Print the solution as well as the problem
`marks`	Print the mark scheme (for assignment questions, for example)
`database`	This option prints problems with their BibTeX reference key
`biber`	Use `biber` as the backend (rather than `bibtex`).

Any other options given will be passed to the package `biblatex`. We have seen the effect of the `solution` option. The `database` option will list the problems indexed by their BibTeX keys. For example

2-1 The one dimensional (linear) wave equation is given by

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2} \tag{1}$$

where c is the (constant) wave speed. Show that this equation may be rewritten as the coupled system of two first order equations

$$u_t - c\,u_x = w$$
$$w_t + c\,w_x = 0.$$

Hence show that the general solution of (1) is

$$u(x,\ t) = F(x - ct) + G(x + ct)$$

for arbitrary functions F and G.

Note that multiple options may be specified.

If the database is not in the same directory as the `.tex` file (or not on the `TEXINPUTS` path) then its directory needs to be path given

```
\InputDir{C:/tex/361/Problems/}
```

(with the correct path, of course). This argument may be a comma delineated list of directories. LaTeX will append these directories to the search path for databases, input (and include files) and graphics files. `\VerbInput` will search this path and input the file using `\VerbatimInput` (assuming that the package `fancyvrb` is loaded). Next the name of the database (without the `.bib` extension) is required (and this can be a list of databases)

```
\Database{SampleDatabase}
```

At this stage you can produce a document with your preferred formatting. Problems are referenced by `\problems`. Its argument is a comma separated list of BibTeX keys (or * for all entries in the database). This command has several options:

`prefix`	Prefix the problem number with given character(s)
`keyword`	Select only those arguments whose keywords field contains the given keyword
`notkeyword`	Select only those arguments whose keywords field do not contain the given keyword
`solution`	This will print the solutions to the selected problems

The prefix option may be used, for example, to star certain problems

```
\problems[prefix=*]{1-1,1-2}
```

If more than one `keyword` or `notkeyword` options are given then the result is all entries that satisfy all the options. For example

```
\problems[keyword=exam,notkeyword=2009]{*}
```

will produce a file that contains all problems in the database that have `exam` but not 2009 in their `keywords` field.

4 Format Options

There a number of builtin format options. A minimalist approach is given by

```
\documentclass{article}
\pagestyle{empty}
\usepackage{problems}

\Database{SampleDatabase}
\Course{MATH109}
\Year{09}
\Occurence{S2}
\TutorialNumber{11}
\TutorialDate{October 11-15}
\Instructions{Please hand your solution to the starred problem
                    your tutor at the end of the tutorial.}

\begin{document}

\tutorial{S1,S2}
\problems[prefix=*]{S3}

\end{document}
```

which will produce

MATH109-09S2 Tutorial 11

October 11-15

Please hand your solution to the starred problem to your tutor at the end of the tutorial.

11.1 Show that the series

$$\sum_{k=1}^{\infty} (-1)^k \frac{\log k}{k}$$

converges. Does it converge absolutely?

11.2 Is the series

$$\sum_{k=1}^{\infty} \frac{(-1)^{k+1}}{\sqrt{k+1}+\sqrt{k}}$$

absolutely convergent, conditionally convergent or divergent?

*11.3 Is the series

$$\sum_{k=1}^{\infty} \frac{(-1)^{k-1}\, 3^{2k-1}}{k^2+1}$$

absolutely convergent, conditionally convergent or divergent?

The \tutorial command is an interface to the \problems command but prefaces it with \TutorialHeader. This header is form from the following commands (all of which are optional).

\Tutorial	Title (default: Tutorial)
\Course	Course code
\Year	Year
\Occurence	Semester
\TutorialNumber	Tutorial Number
\TutorialDate	Date(s) of tutorial
\Instructions	Text to be inserted between Title and first problem
\TutorialHeader	The standard header formed from the above options

The default problem numbering is determined by \TutorialNumber. This may be overridden by giving an optional argument to this command. For example

```
\TutorialNumber[]{11}
```

will number the problems 1, 2, 3 and so on. Of course the formatting can be specified directly using LaTeX. There are a number of other formatting options

\nolabels	Turns off the default problem numbering
\SolutionFormat	Format to print solution
\AtEndSolution	Commands to execute at end of a solution (default: \newpage)
\MarksFormat	Format to print marks scheme (default: \bf)

For example, the command

```
\nolabels
```

turns off the automatic numbering of the problems. The user can then number problems using standard LaTeX constructions. In order to align numbering correctly, use the questions environment for the outer enumeration. For example

```
\begin{document}
\TutorialHeader
\nolabels
\begin{questions}

\item \begin{enumerate}
\item \problems{S1}
\item \problems{S2}
\end{enumerate}

\starred \problems{S3}

\end{questions}
\end{document}
```

will yield

MATH109-09S2 Tutorial 11

October 11-15

Please hand your solution to the starred problem to your tutor at the end of the tutorial.

1. (a) Show that the series

$$\sum_{k=1}^{\infty} (-1)^k \frac{\log k}{k}$$

converges. Does it converge absolutely?

(b) Is the series

$$\sum_{k=1}^{\infty} \frac{(-1)^{k+1}}{\sqrt{k+1}+\sqrt{k}}$$

absolutely convergent, conditionally convergent or divergent?

***2.** Is the series

$$\sum_{k=1}^{\infty} \frac{(-1)^{k-1}\, 3^{2k-1}}{k^2+1}$$

absolutely convergent, conditionally convergent or divergent?

Note that the `prefix` key will no longer be actioned. Star is achieved by `\starred` This command takes an optional argument which will replace the star. Thus

```
\starred[**]
\starred[$\dagger$]
```

will place a double star and a † in front of the item label respectively. The command

```
\SolutionFormat{\relsize{-1}\color{red}}
```

will print the solution in red in a font size reduced by 1 step (this assumes that the `relsize` package is loaded). The command

```
\AtEndSolution{}
```

will remove the default `\newpage` at the end of the solution. Personal defaults may be stored in a file `problems.cfg` on the LaTeX path.

Producing the File

In order produce the final output `sample.pdf`, the following commands (assuming that the `biber` option is not used) need to be executed:

```
pdflatex sample
bibtex8 -W sample
pdflatex sample
```

with the final call to pdflatex repeated as many times as necessary to resolve all forward references. Due to the size of a typical problems database, bibtex8 is used (rather than bibtex) and is called with the "wolfgang" switch. If the biber option is used then the bibtex8 command is replaced by

```
biber sample
```

5 What you need

The files that are needed but not in the standard repositories are bundled in the archive problems.zip available from www.math.canterbury.ac.nz/~m.hickman/LaTeX/problems.zip. This archive contains

problems.sty	Placed on the $TEXINPUTS path, typically in the texmf/local directory tree
question.bst	BibTeX style file. Again placed in the texmf/local directory tree
question.xml	JabRef configuration file
tutorialskel.tex	A template for generating tutorial sheets
ProblemsManual.pdf	This file

In addition, if not already installed, bibtex8, biblatex and etoolbox are needed. These are available from the standard repositories including TeXLive and MikTeX. Note that this package requires e-TeX binaries. Most recent distributions default to these binaries. If you have problems, try elatex or pdfelatex. If that fails it may be time to update your TeX installation.