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 \bq \pder[2]{u}{t^2}
        = c^2 \, \pder[2]{u}{x^2} \label{wave} \eq 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

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

$$u_t - c\,u_x = w$$
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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 given

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

(with the correct path, of course). Next the name of the database (without the `.bib` extension) is required

```
\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

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

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 numbering of the problems. The user can then number problems using standard LaTeX constructions. 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.

Producing the File

In order produce the final output sample.pdf, the following commands 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.

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 TeXLive2009 and TeXLive2010 . 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.