Assessment of e-Mathematics with Maple

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Abstract: In our mathematics courses, computer laboratory sessions with Maple are being used to fundamentally change the way we teach. Sophisticated computer algebra systems (CAS) such as Maple (and Mathematica) can do it all: numerical computation, symbolic manipulation, graphics (visualization and animations), word processing, programming and communication (via internet). This can be exploited not only in the teaching and learning of mathematics, but also in the assessment. We discuss our assessment experience with several first year courses (where Maple supports a traditional approach) and third year courses (run in Maple "immersion" mode where everything is done with Maple).

Our students have done some calculus at high school, so we have, since 1998, a first year course, Nonlinear Mathematics, that is taken concurrently with a fairly standard type of calculus subject. The nonlinear mathematics subject introduces some modern ideas, namely Phase Plane Methods and Iteration, and the use of Maple is integrated throughout this subject. Animation is introduced in this subject and students must, in small groups, choose an animation project and present their animation (in the lab) for assessment. The assessment is demanding of staff time but is almost a tutorial. We would like to do more in this style although it is difficult to do so "efficiently".

With the first year "calculus +" courses, Maple is used in separate lab sessions to support traditional first year courses. We use Blackboard to post the teaching and assessment materials (Maple files) on the web. We discuss in detail two assignments that have been individualized for each small group. Students submit their solutions, as Maple files, to proxy email accounts. They are marked with the overall marks distribution and detailed comments interspersed throughout the Maple file – all in a new paragraph style, coloured dark green. The marked Maple files are emailed back to each student.

One of these assignments focuses on numerical integration using trapezoidal and Simpson's rules. After careful analysis of student work, we will now re-design this to be submitted and marked by AIM – a computer based assessment system that uses Maple to interrogate the answers and provide feed back for particular errors (in how Simpson's rule has been incorrectly programmed).

Another individualized assignment is where students use our version of the Polya type of problem solving approach using Maple to maximize the area in the Norman window problem. A labeled diagram is required – something that computer aided assessment (CAA) programs don't help with! We emphasize that Maple files should include graphics and a "write-up" and propose that CAA tools should provide a semi-automatic marking mode where some text and graphics can be marked by the lecturer with the computations (symbolic and numeric) marked automatically.

We conduct third year courses in Vector Calculus, Geometry of Surfaces and Finite Element Methods in Maple immersion mode and discuss our experience with CAS assessment: Maple assignments and examinations, some of which have been individualized. We find that grading e-examinations takes similar staff resources as the usual marking of hardcopy scripts.

1. Introduction

Sophisticated computer algebra systems (CAS) such as Maple (and Mathematica) can do it all: numerical computation, symbolic manipulation, graphics (visualization and animations), word processing, programming and communication (via internet). This is being exploited not only in the teaching and learning of mathematics, but also in the assessment. In this paper we discuss our assessment experience with several courses where assignments and examinations use Maple and communications technology (Web and e-mail).

Our assignments are often done in small groups and are usually individualized for each group. We have also introduced an individualized question for an examination, see the section below on e-Assignments and e-Examination for Vector Calculus. For small classes, our experience (and feedback from students) indicates that copying is not a problem. However for a large enrolment course (see the section below on e-Assignments for the Finite Element Method), copying was a problem.

For our e-assignments and e-examinations we require write-ups and plots and this is marked (as discussed below) from the Maple files (and no hardcopies). Given that the student work is individualized, and returned work has extensive feedback included in the Maple files, the assessment load on staff is probably “similar” to that in more traditional courses.

There has been a lot of work done with computer aided assessment and a vast literature exists. Multiple choice question systems are still in use (online), sometimes in creative ways, see [6] for a discussion. For a different view, see [5] where a distinction is made (and investigated) between multiple choice questions and provided response questions. We are not enthusiastic about these approaches since they are limited. The advent of Computer Aided Assessment, CAA, which uses a Computer Algebra System, CAS, (such as Maple or Mathematica) greatly extends the assessment tool. For an introduction to this literature, see the CAA Series [7], with monthly articles and discussion posted. We have developed a version of our trapezoidal rule and Simpson rule e-assignment as an AIM question. AIM is a web based CAA system using Maple that gives correct mathematical typesetting (via LaTeX) and includes features such as partial marks and diagnostic feedback, see [8] (and also [9]) for a good introduction to the current version (of AIM: written by Neil Strickland of the University of Sheffield).

Since we insist that students provide write-ups and plots, we propose that a further extension of CAA such as AIM could allow extra response types of (1) text input and (2) plots, which are not marked automatically, but by the lecturer. We refer to this as a **Lecturer Interactive CAA**, LICAA, and discuss how this could be used for most of our e-assessments (but not all).

2. e-Assignment for animations

A first year course, Nonlinear Mathematics, is taken concurrently with a fairly standard type of calculus subject and introduces some modern ideas, namely Phase Plane Methods and Iteration. The use of Maple is integrated throughout this subject. Animation is introduced in this course and used by the lecturer in presentations (for example with iteration diagrams for Newton’s method and fixed point iteration), see [1]. Students must, in small groups (of size 2,3 or 4), choose an animation project (from a list of five) and present their animation (in the lab) for assessment. All members of the group must be present for the assessment presentation and each is asked to contribute to the animation demonstrations and the discussion.

Students enjoy this and have lively discussions about the application! A reasonable attempt gets a mark of 3 out of 5. Something beyond a basic animation (for example, dynamic labeling of the parameter value) plus a lively and informed discussion about the context and application of the problem is expected for a higher mark. The most popular problems are Problem 3 (on animations concerning the modeling of drug concentration in the blood) and Problem 2 (on functions equal to zero at two boundary points and applications to guitar strings and heat flow), followed by Problem 5 (a follow up from an exercise in the Newton Method worksheet: animating the flight of a projectile with wind resistance and determination of the range). A few also choose to do Problem 4 (on animating the secant approaching the tangent).

The assessment is demanding of staff time since the class size is about 60 (with both authors present in the lab) but is almost a tutorial. We would like to do more in this style although it is difficult to do so "efficiently" – it is hard to see how any computer aided assessment package could contribute here.

3. e-Assignment for Simpson's rule and Computer Aided Assessment

The fairly standard type of calculus subject taken in first semester concurrently with Nonlinear Mathematics (see the previous section) finishes with a small (6 contact hours) Maple topic. There are two assignments, the first of which is on Simpson's rule. This student group has already done some Maple, including some simple programming for Newton's method and fixed point iteration and have also had a traditional lecture on numerical integration. They then had an additional Maple presentation on trapezoidal rule and were given help in the lab on Maple Assignment 1, reproduced below.

Maple Assignment 1

for the mathematics Degree and Dual Award group

The Assignment:

In a group of size 2 plus or minus 1, prepare a worksheet which has a title, authors (name and student number) and solution for the following.
Note: Your solution MUST include some brief explanation and write-up!

Submit by e-mailing to
ma-maths@ems.rmit.edu.au
with subject
A1 - familyName1, familyName2
(where all the familyNames are given IN ALPHABETICAL ORDER)
with no message, and
attach the Maple file (IN THE OLD .mws FORMAT - i.e. using Maple 6, 7, 8 or "classic" 9).

by 8pm Wednesday May 19, 2004.

Preliminary

Following the trapR.mws worksheet,
copy and paste the procedure trap:=proc(a,b,n) AND **provide some CHECK** that it is running correctly.

Question 1

Define your group number, gpN, as the average value of the last digit of the student numbers
(for example, if your student numbers are mm...m8 and nn...n5, then gpN = $\frac{8+5}{2}$).

Note: if your last digit(s) is zero, then use the second last digit (so that gpN is NOT zero).

Define

$$f := x \to (x^2 + gpN)^{\left(\frac{7}{2}\right)}$$, a = 0, b = gpN.

Consider the integral $\int_a^b f(x)\, dx$ and the trapezoidal approximation for this integral.

1. Use a log log plot of trapezoidal method error versus n to show that the error follows a power law.
2. Given that the error follows a power law: error = constant $* \; n^{(-p)}$;
calculate the p here to check that p is (approximately) the same as before (in the trapezoidal rule worksheet provided: trapR.mws).
Hint: remember to change the definition of exact for this new problem.

Question 2

Redo Question 1.1 after editing the plot command so that n is doubled each time, from n = 2, 4, 8, ... , 1024.
Hint: the seq( ) command is usually used as seq(f(i), i=iStart..iFinish) where iStart and iFinish are integers and the i values used are iStart, iStart+1, iStart+2, iStart+3, ... , iFinish. This approach can be used here after suitably writing n in terms of i ... .

Question 3

1. Edit the trap() procedure to calculate the Simpson method approximation (and CHECK!!).
Remember that n must be an even number for Simpson's rule.
Remember that the total Simpson rule area is the sum:
Simp = h /3 (f(a)+4 f(a+h) +f(a+2h)) + h/3 (f(a+2h)+4 f(x+4h)+f(x+3h)) + ...
= h /3 [f(a) +f(b) + 4 (f(a+h)+f(a+3h)+f(a+5h)...) + 2 (f(a+2h)+f(a+4h)+...)]
= h/3 [f(a) +f(b) + 4 sum(f(a+h)+f(a+3h)+ etc) +2 sum(f(a+2h)+f(a+4h)+ etc)]

2. Use a log log plot of Simpson method error versus n to show that the error follows a power law.
Hint: only use n as the powers of 2 between 2 and 128.
3. Calculate the p (the power of the error power law: error = constant $* \; n^{(-p)}$) here.

Students were able to download the lecture files (such as trapR.mws) and the assignment (as a Maple file) from the Web using Blackboard.

For marking, we spent about two hours discussing our new approach and pre-preparing the text comments that we anticipated would be appropriate. In the lecturer’s solution file, a Marking section holds a collection of all of the comments inserted into the student files and a template marks summary in green text cells that were easily recognizable from the usual Maple black text, red input and blue output: a brief sample is given in section 4 below. The assignment Maple files were opened (from the email proxy account), comments, marks and feedback inserted; and returned by e-mail.

The marking took about 6 hours for 27 submissions. A rate of 5 per hour might seem a little slow, but it should be remembered that the assignments were individualized: the solution file was executed for each student group’s submission. It is important to note that the comments, cut and pasted, for feedback were more extensive than would have been provided had the work been marked “by hand”.

Performance on Questions 1 and 2 (on the trapezoidal rule) was good, but many errors were made on the Simpson’s rule question. These have been collected and analyzed. Common mistakes were getting the gpN wrong, trouble with getting the number of even and odd terms correct and with adjusting the formula for correct weights (1 4 2 4 2 … 4 1). We elaborate: from the trapR.wks, (available for download) the tested trap( ) procedure is

```
> trap:=proc(a,b,n)     # requires f(x) defined as a fn
    local h;
    h:=evalf((b-a)/n);
    h*( evalf(f(a)+f(b))/2 + add(f(a+i*h), i=1..n-1) );
  end:
```

The adjusted line for Simpson's rule is

```
> h/3*( evalf(f(a)+f(b)) + 4*add(f(a+(2*i-1)*h), i=1..n/2)
    + 2*add(f(a+2*i*h), i=1..n/2-1) )
```

A common error was to neglect to change the addition index so that about twice as many terms as required were added! Another was to use n/2 but neglect to notice that the number of terms with coefficient 4 is different to the number of terms with coefficient 2.

Although the staff resources required for this e-assignment are reasonable, we are investigating more efficient approaches where the computer can assist with the marking. The AIM system, see [8], is Web based and uses Maple as its CAS and a LaTeX representation for a proper display of the mathematics on the Web page. AIM is appealing also because its capacity to be used for diagnostic error detection that can be accompanied by detailed feedback to the student. We have implemented this assignment as a CAA assignment using AIM. We can detect the main errors in the Simpson's rule procedure from the students answer and thus provide the appropriate feedback (and marks).

With the full Maple files emailed to the staff, it is clear that the required check (with exact result) to check the Simpson rule procedure was often absent. It is not clear how to use AIM to ensure that the use a check is detected. We will address this issue and expect that we can find a way to deal with this. In this case providing some extra instruction would be acceptable to us.

However there are two important characteristics of our e-assignments and e-examinations that appear to be outside the CAA systems currently available. These are write-up and graphics (and are recurring themes throughout this paper). We usually require students provide appropriate comments and a write-up. For example, we want students to write something about the meaning of a nearly straight line fit of data (such as trapezoidal or Simpson rule errors) in a log log plot. We also usually require appropriate graphs and we do not want to be too prescriptive – for example students may be expected to be able to determine a suitable domain for the plot. We allocate marks for write-up and graphics.

We are not prepared to compromise our assessment objectives much in order to utilize a CAA tool. We propose that CAA should be extended to add a lecture interactive component – a **Lecturer Interactive CAA**, LICCA. We suggest that a CAA system such as AIM could be extended to allow extra response types of (1) text input and (2) plots, which are not marked automatically. After the closing date of the assignment, the lecturer could view each such response and allocate a mark (and feedback text) to be added to the automatically marked responses. The lecturer could do this very efficiently and achieve almost unconstrained assessment objectives (with diagnostic feedback).

A further example from the Simpson's rule question: despite having the Maple file using the add() command, several students wrote traditional procedural code instead of producing simpler code by just editing the provided trapezoidal rule procedure. We did not penalize students for this but did provide feedback. Our AIM version of the assignment only interrogates answers produced from the code, so we are unable to provide comments about the elegance of the code. AIM does not allow Maple code as input – one reason is that AIM is executed using Maple and so the system needs to be protected from "unfortunate" or "nasty" Maple code. With a LICAA system proposed here, the procedure could be inserted as text input and the lecturer could simply view it, or copy to a separate Maple kernel for execution.

Assignment 2 is also individualized where students use our version of the Polya type of problem solving approach using Maple to maximize the area in the Norman window problem. A labeled diagram is required. Students do well on this assignment and the most difficult part for them is the plot. We will prepare an AIM version of this assignment and this will not require many compromises – we will provide a plot labeled with words and ask students to enter their variable definitions. However we will not be able to get the students to give us their plot via AIM (unless a LICAA version is developed).

4. e-Examinations

Geometry of Surfaces is course of classical differential geometry has been traditionally taken by all of the surveying students in the third year of their program which is now a four year degree. For nearly 30 years, Geometry of Surfaces was taught (in classes of about 30) by two lectures per week with several paper and pencil optional assignments (not for credit) and examination. This course requires exact (or "symbolic") computation and is also a rich subject for the incorporation of visualization. We use Maple in our presentations in class and the students do all of their work with Maple in the computer laboratory.

In 1998, the first computing laboratory version was introduced using Mathematica. However, since we have a site licence for Maple, the course has been rewritten and developed using Maple since 1999. The two lectures per week were replaced by one lecture and one lab session. The lectures were initially given in standard mode using an overhead projector and hand written transparencies without any use of CAS. From 2003, the earlier Maple worksheets were rewritten and expanded to be used for the lectures and Maple was used as the presentation medium. This worked well and the students seemed to be much more comfortable with the use of the CAS, see [4].

In the first week of classes in 1998, students were consulted about assessment. There seemed to be little point in requiring either the assignment work or the examination to be done by paper and pencil when one of the major objectives was develop skills in the application of a modern CAS software package. Traditionally, since this is a third year course, the assignments did not contribute to the assessment grades. After having a week to think over various options, the students readily agreed to no assessment for the "assignment" work and 100% assessment on a final examination to be held in the computer laboratory using Mathematica.

Mostly, the optional assignments were emailed as Maple file attachments to e-mails with feedback provided electronically (as well as tutorial assistance during the laboratory sessions). The examination requires the use of Maple and is conducted in the computer laboratory.

A standard student feedback questionnaire (copy available on request) was given to students in the last teaching week. This was in two parts. Part A had 11 statements which students are invited to express agreement or disagreement on a 5 point Likert scale. Part B asked for comments to questions. The most interesting feedback were the free responses to two of the Part B questions. The typical response to **"What do you like most about this course?"** was "assessment based on exam only" and the second most popular response was "learning to use Maple which is quite useful". Our personal favourite was "I understood what was going on".

Responses to **"What would you change to improve the course?"** were mostly similar to "Have small assignments to better develop understanding" (sometimes Maple was mentioned explicitly). A couple of responses suggested that "lectures scrapped and 2 hours of lab so we have a computer in front of us to follow. Very easy to get lost in lectures – thus we lose concentration”. As a result we are teaching the next semester course (also a “Maple immersion course”) in mini lectures interspersed with student work in a two hour block in the lab in an attempt to address these issues. It appears that our approach will be quite similar to that of Jerry Uhl and his co-workers (see [10]: Why (and how) I teach without long lectures).

After the examination results for 2004 were published, one of the students was asked for comments about the course. These included “Maple was difficult to start with, but glad he did the course – lecture presentation was clear – glad he has done some Maple – it took a while to learn Maple, so glad there were no assignments, just exam”. In response to a question regarding students cheating or copying, he was not aware of such.

Initially, from 1998 to 2002, the examination paper was a hardcopy typeset using LaTeX. In view of the software focus and the increasing use of communications technology for online delivery, the examination paper in 2003 was a Maple file provided both as a hardcopy and in electronic form. In 2004, only the e-copy of the examination paper was provided. The Maple e-examination worksheet was provided on floppy disks that were distributed to the students in the examination. They submitted their examination answers as Maple files labeled as Q1, Q2, Q3 and Q4 on the floppies that had been supplied. Students were encouraged to do their work in their home directory and then save their final answers there (for their records) and on the floppy disk (for submission). These solutions were not printed out as hardcopies by either the candidates nor the lecturer. They were marked by viewing the worksheets using Maple and notating a hardcopy mark sheet.

For examination preparation, the students are given two previous past papers from about a decade ago with fully worked “by hand” solutions of the questions appropriate for the laboratory examination. Students are invited to prepare CAS template solutions and save as files which will, with some editing, be suitable for the solution of the (closely related) examination questions. Electronic CAS solution file have been deliberately withheld since the students are required to prepare the template examination answer files from the provided teaching materials as part of their learning process. The students were allowed all handouts and their own work by paper and electronically.

Typically, students find dealing with Maple and new course content difficult at the start of the laboratory sessions, but perform well at the examination. Pre-CAS typical classes were, for example, the 1985 class (size 25, pass rate 76%, high grades 20%) and 1994 (size 32, pass rate 84%, high grades 22%) where the high grades means the top two of the four passing grades. Typical of CAS classes was the class of 2000 (size 28, pass rate 86%, high grades 46%) and the class of 2004 (size 25, pass rate 92%, high grades 52%). In summary, with the introduction of the CAS, the pass rates have increased slightly and the performance at the high end has improved with the proportion of higher grades more than doubled.

5. e-Assignments and e-Examination for Vector Calculus

For the first time in 2002, the Vector Calculus Methods for Geospatial Scientists was offered in Maple immersion mode, see [3]. The student group had completed the Maple immersion course Geometry of Surfaces in the previous semester. An objective was to cover the same material as previously, but to take advantage of the tool (namely, the CAS package Maple). The assessment was 50% on four assignments and 50% by examination in the computer lab using Maple.

The lecturer opened the assignment Maple files and inserted comments, marks and suggestions for fixing problems in green text cells that were easily recognizable from the usual

Maple black text, red input and blue output; and returned the files by e-mail. In the lecturer's solution file, a Marking section holds a collection of all of the comments inserted into the student files and a template marks summary: a brief sample follows.

marks: (out of 10) 8
made up roughly (an indication only!) by
write up (out of 1) 0
Q1 (out of 1+1+1+1=4) 4
Q2 (out of 1+1+2+1=5) 4

This is not a good choice for the plot region - it would be better to avoid having the point on an edge of your plot!

A bit messy! Tidy up your write-up a bit!

Some individualization for Assignment 2 was used and some this was also implemented for the 2003 examination: Question 1 (a Section of the Maple e-examination file) is reproduced below.

Question 1
Define your special number, sN, as the value of the last digit of your student number (say sN = 5). (Thus the value of sN is an integer between zero and nine.)

Define the function ϕ (a scalar field) by

$$\phi := -20\cos\left(\frac{(x^2+y^2)\,\pi}{5}\right) - z + \frac{y^2}{sN+1}\ .$$

Consider the point P(-1, 2, sN).

(a) Which level surface of ϕ does the point P lie on?
(b) Plot the level surface in part (a) AND the point P on the same diagram.
(c) Find the directional derivative of ϕ at P in the direction of **i** + **j** - **k**.
(d) In what **direction** does ϕ increase most rapidly at P?

(5+5+10+5 = 25 marks)

The level of difficulty was "identical" with the previous pen and paper course and examination. For the individualization here, the lecturer's solution Maple file included simple loops to produce lists of answers for the parameter sN for ease of marking. The marking rate for the e-examination was about the same as for the old paper and pencil examinations. For this course, the class size is about 25 and there appears to be no problem with copying (unlike the FEM course discussed next).

6. e-Assignments for the Finite Element Method

The Finite Element Method, FEM, is a course for third and fourth year engineers run as in "Maple+ immersion" mode with a component using the commercial software FEM package ANSYS, see [2]. Assessment is by two Maple assignments, a test and an ANSYS assignment. All the Maple teaching files are downloaded by students from a password protected server and the two assignments, as Maple files, are emailed to students via a student list. The summer course is an intensive course over two weeks with lectures and lab sessions throughout the first week and the second week mostly lab access with consultation (in the lab) for the students to complete their assignments.

This course is popular (with about 500 students each year) and has high pass rates. The grade distributions (where HD = High Distinction, DI = Distinction, CR = Credit and PA = Pass) for the last three years summer courses are

Year	class size	HD	DI	CR	PA	pass rate
2002	98	14%	29%	37%	18%	98%
2003	57	14%	46%	22%	15%	97%
2004	92	9%	22%	41%	23%	95%

In 2004 a new feature was introduced: both of the Maple assignments were individualized. The assignments asked for a particular boundary value problem, BVP, to be solved with various techniques: collocation method and Galerkin method using polynomials for Assignment 1 and piecewise linear FEM for Assignment 2.

The BVP. The electrostatic potential, u = ϕ , in the gap (with x = r, the radial distance) between 2 long coaxial metal cylinders is described by the two-point boundary value problem

$$\frac{d}{dx}\left(x \frac{du}{dx} \right) = 0 , \quad \text{for } R_1 < x < R_2$$

subject to the boundary conditions $\phi(R_1) = \phi_1$ and $\phi(R_2) = \phi_2$, where ϕ_1 and ϕ_2 are constants.

Students were asked in 2004 to complete the assignment in pairs (although individually is allowed) with the parameters R_1, R_2, ϕ_1 and ϕ_2 defined in terms of the student numbers of the pair. This was introduced because of concerns about student copying of work: indeed, for the same reason, the test was introduced in 2000 (and replaced a third Maple assignment in the original course). Students emailed their Maple files as solutions of the assignments to an email proxy account and were marked by viewing the student file with one Maple kernel, with the lecturer's solution file active in another Maple kernel. Thus the student parameters were inserted into the lecturer's solution file and executed. A hardcopy mark sheet was annotated and used to determine grades – no feedback was provided to students unless they asked for it (by email or in person). Our experience over the years is that the students rarely collected their marked FEM assignments. The marking effort has always been substantial. In the past, marking hardcopy assignments (of the same problem) could be done at a rate of about 4 to 6 per hour while marking the individualized e-assignments achieved was done at about 4 per hour.

The introduction of individualized assignments was prompted by concerns about student copying and it appears to have successfully addressed this issue. The grade distribution (given above) clearly indicates that the high pass rates were maintained, but there was a reduction in the percentage of higher grades. Also, the course is run in an intensive mode over two weeks where the second week is reserved for lab access and consultation (to complete the assignments). There was a sharp increase in requests from students for assistance: up from about an hour or less each day to about three hours each day!

Since the assignments have a mixture of numerical computation, plots (of the error over the interval, and fits to test theoretical error behaviour), some theory parts and marks allocated for "write-up", it is difficult to see how the marking can be done with CAA. We want to explore the idea of a lecturer interactive computer aided assessment approach, LICAA, for FEM.

7. Conclusion

Doing mathematics is now often supported by the use of a CAS such as Maple or Mathematica. We have been using Maple to fundamentally change the way that we teach and assess our mathematics students. The solution to our e-assignments and e-examinations are Maple files and are often individualized. The marking load, particularly for large courses, is always an issue. We have started to investigate the use of CAA and have implemented an AIM version of one of our e-assignments (and planned another, soon to be implemented) which include detailed diagnostic feedback.

However our teaching approach emphasizes the inclusion of write-ups and plots and these are difficult to computer mark automatically. We propose to investigate a **Lecturer Interactive CAA**, LICAA, where the lecturer could interactively mark the text comments and the plots. We suggest that this would allow for very efficient marking, with diagnostic feedback, that would satisfy almost all of our assessment objectives with very little compromise of those objectives.

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