CARMA and Me

prepared for

CRM/UWS Opening 28-05-2014

(and CARMA Annual Retreat)

Jonathan M. Borwein FRSC FAA FBAS FAAAS

Laureate Professor & Director of CARMA, University of Newcastle

URL: http://carma.newcastle.edu.au/jon/vc-visit13.pdf

NEWS: http://carma.newcastle.edu.au/carmanews.shtml

Priority Research Centre for

Computer **A**ssisted **R**esearch **M**athematics and its **A**pplications

Revised: May 22, 2014

Title with apologies to:

Michael Moore: *Roger and Me* (1989)

Paul Erdös: *Ramanujan and Me* (1987)

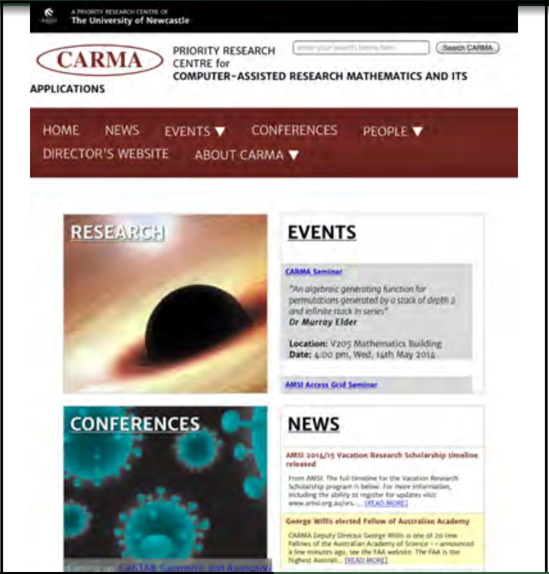
Congratulations to All

Contents

we will *sample*

CARMA

CARMA Home Page



CARMA

CARMA's Leadership

... diversity

- Government, Industry and Academia: Australia and Overseas
- All have close connections with Newcastle

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CARMA's Support Staff

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- They make our activities possible
  - with unfailing good grace, imagination and energy

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Computer Assisted Research Mathematics: what it is?

Experimental mathematics is the use of a computer to run computations—sometimes no more than trial-and-error tests—to look for patterns, to identify particular numbers and sequences, to gather evidence in support of specific mathematical assertions that may themselves arise by computational means, including search.

Like contemporary chemists—and before them the alchemists of old—who mix various substances together in a crucible and heat them to a high temperature to see what happens, today's experimental mathematicians put a hopefully potent mix of numbers, formulas, and algorithms into a computer in the hope that something of interest emerges. (JMB-Devlin, 2008, p. 1)

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Top Ten Algorithms: all but one well used in CARMA

Algorithms for the Ages

"Great algorithms are the poetry of computation," says Francis Sullivan of the Institute for Defense Analyses' Center for Computing Sciences in Bowie, Maryland. He and Jack Dongarra of the University of Tennessee and Oak Ridge National Laboratory have put together a sampling that might have made Robert Frost beam with pride--had the poet been a computer jock. Their list of 10 algorithms having "the greatest influence on the development and practice of science and engineering in the 20th century" appears in the January/February issue of Computing in Science & Engineering. If you use a computer, some of these algorithms are no doubt crunching your data as you read this. The drum roll, please:

1. **1946: The Metropolis Algorithm for Monte Carlo.** Through the use of random processes, this algorithm offers an efficient way to stumble toward answers to problems that are too complicated to solve exactly.
2. **1947: Simplex Method for Linear Programming.** An elegant solution to a common problem in planning and decision-making.
3. **1950: Krylov Subspace Iteration Method.** A technique for rapidly solving the linear equations that abound in scientific computation.
4. **1951: The Decompositional Approach to Matrix Computations.** A suite of techniques for numerical linear algebra.
5. **1957: The Fortran Optimizing Compiler.** Turns high-level code into efficient computer-readable code.
6. **1959: QR Algorithm for Computing Eigenvalues.** Another crucial matrix operation made swift and practical.
7. **1962: Quicksort Algorithms for Sorting.** For the efficient handling of large databases.
8. **1965: Fast Fourier Transform.** Perhaps the most ubiquitous algorithm in use today, it breaks down waveforms (like sound) into periodic components.
9. **1977: Integer Relation Detection.** A fast method for spotting simple equations satisfied by collections of seemingly unrelated numbers.
10. **1987: Fast Multipole Method.** A breakthrough in dealing with the complexity of n-body calculations, applied in problems ranging from celestial mechanics to protein folding.

From *Random Samples*, Science page 799, February 4, 2000.

Experimental Mathematics: Integer Relation Methods

Secure Knowledge without Proof. Given real numbers $\beta, \alpha_1, \alpha_2, \ldots, \alpha_n$ Ferguson's integer relation method (**PSLQ**), finds a nontrivial linear relation of the form

$$a_0\beta + a_1\alpha_1 + a_2\alpha_2 + \cdots + a_n\alpha_n = 0, \qquad (1)$$

where a_i are integers—if one exists and provides an exclusion bound otherwise.

- If $a_0 \neq 0$ then (1) assures β is in rational vector space generated by $\{\alpha_1, \alpha_2, \ldots, \alpha_n\}$.
- $\beta = 1, \alpha_i = \alpha^i$ means α is algebraic of degree n
- **2000** *Computing in Science & Engineering*: PSLQ one of top 10 algorithms of 20th century

(**2001** CISE article on *Grand Challenges* (JB-PB))

PROFILE: HELAMAN FERGUSON

Carving His Own Unique Niche, In Symbols and Stone

By refusing to choose between mathematics and art, a self-described "misfit" has found the place where parallel careers meet

CMS D. Borwein Prize

Madelung constant (**2013** book)

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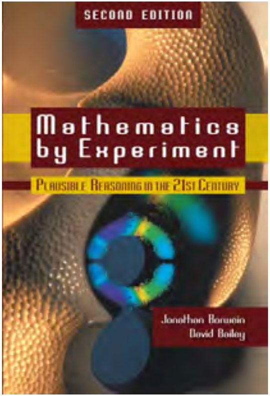
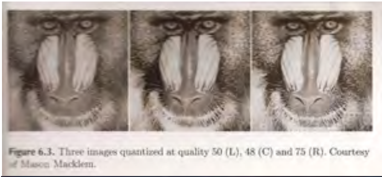
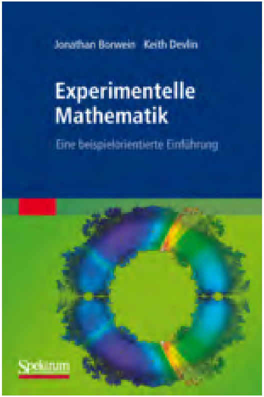
Experimental Mathematics: PSLQ is core to CARMA







Experimental Mathematics (2004-08, 2009, 2010)

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Notices of AMS 2011: … and hundreds of online re-publications

Exploratory Experimentation and Computation

David H. Bailey and Jonathan M. Borwein

> The authors' thesis—once controversial, but now a commonplace—is that computers can be a useful, even essential, aid to mathematical research.
>
> —Jeff Shallit

Jeff Shallit wrote this in his recent review (MR2427663) of [10]. As we hope to make clear, Shallit was entirely right in that many, if not most, research mathematicians now use the computer in a variety of ways to draw pictures, inspect numerical data, manipulate expressions symbolically, and run simulations. However, it seems to us that there has not yet been substantial and intellectually rigorous progress in the way mathematics is presented in research papers, textbooks, and classroom instruction or in how the mathematical discovery process is organized.

Mathematicians Are Humans

We share with George Pólya (1887–1985) the view [25, vol. 2, p. 128] that, while learned,

> intuition comes to us much earlier and with much less outside influence than formal arguments.

Pólya went on to reaffirm, nonetheless, that proof should certainly be taught in school.

We turn to observations, many of which have been fleshed out in coauthored books such as *Mathematics by Experiment* [10] and *Experimental Mathematics in Action* [1], in which we have noted the changing nature of mathematical knowledge and in consequence ask questions such as "How do we teach what and why to students?", "How do we come to believe and trust pieces of mathematics?", and "Why do we wish to prove things?" An answer to the last question is "That depends." Sometimes we wish insight and sometimes, especially with subsidiary results, we are more than happy with a certificate. The computer has significant capacities to assist with both.

Sinail [27, p. 113] writes:

> the large human brain evolved over the past 1.7 million years to allow individuals to negotiate the growing complexities posed by human social living.

As a result, humans find various modes of argument more palatable than others and are more prone to make certain kinds of errors than others. Likewise, the well-known evolutionary psychologist Steve Pinker observes that language [24, p. 83] is founded on

> the ethereal notions of space, time, causation, possession, and goals that appear to make up a language of thought.

This remains so within mathematics. The computer offers scaffolding both to enhance mathematical reasoning, as with the recent computation connected to the Lie group E_8 (see http://www.aimath.org/E8/computerdetails.html), and to restrain mathematical error.

Experimental Mathodology

Justice Potter Stewart's famous 1964 comment, "I know it when I see it," is the quote with which

David H. Bailey is Chief Technologist of the Computational Research Department at Lawrence Berkeley National Laboratory. His email is dhbailey@lbl.gov. This work was supported by the director, Office of Computational and Technology Research, Division of Mathematical, Information, and Computational Sciences of the U.S. Department of Energy, under contract number DE-AC02-05CH11231.

Jonathan M. Borwein is Laureate Professor at the Centre for Computer Assisted Research Mathematics and its Applications (CARMA) at the University of Newcastle, Australia. His email address is jonathan.borwein@newcastle.edu.au.

The Computer as Crucible [13] starts. A bit less informally, by *experimental mathematics* we intend [10]:

(a) gaining insight and *intuition*;
(b) *visualizing* math principles;
(c) *discovering* new relationships;
(d) *testing* and especially *falsifying* conjectures;
(e) *exploring* a possible result to see if it *merits* formal proof;
(f) *suggesting* approaches for formal proof;
(g) *computing* replacing lengthy hand derivations;
(h) *confirming* analytically derived results.

Of these items, (a) through (e) play a central role, and (f) also plays a significant role for us but connotes computer-assisted or computer-directed proof and thus is quite distinct from *formal proof* as the topic of a special issue of the *Notices* in December 2008; see, e.g., [20].

Digital Integrity: I. For us, (g) has become ubiquitous, and we have found (h) to be particularly effective in ensuring the integrity of published mathematics. For example, we frequently check and correct identities in mathematical manuscripts by computing particular values on the LHS and RHS to high precision and comparing results—and then if necessary use software to repair defects.

As a first example, in a current study of "character sums" we wished to use the following result derived in [14]:

$$\text{(1)}\quad \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{(-1)^{m+n+1}}{(2m-1)(m+n-1)^3} \stackrel{?}{=} 4\,\mathrm{Li}_4\left(\frac{1}{2}\right)-\frac{51}{2880}\pi^4-\frac{1}{6}\pi^2\log^2(2)+\frac{1}{6}\log^4(2)+\frac{7}{2}\log(2)\zeta(3).$$

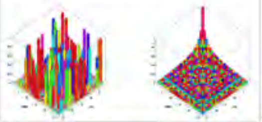
Here $\mathrm{Li}_4(1/2)$ is a polylogarithmic value. However, a subsequent computation to check results disclosed that, whereas the LHS evaluates to $-0.872929289\ldots$, the RHS evaluates to $2.509330815\ldots$. Puzzled, we computed the sum, as well as each of the terms on the RHS (sans their coefficients), to 500-digit precision, then applied the "PSLQ" algorithm, which searches for integer relations among a set of constants [16]. PSLQ quickly found the following:

$$\text{(2)}\quad \sum_{m=1}^{\infty}\sum_{n=1}^{\infty}\frac{(-1)^{m+n+1}}{(2m-1)(m+n-1)^3} = 4\,\mathrm{Li}_4\left(\frac{1}{2}\right)-\frac{151}{2880}\pi^4-\frac{1}{6}\pi^2\log^2(2)+\frac{1}{6}\log^4(2)+\frac{7}{2}\log(2)\zeta(3).$$

In other words, in the process of transcribing (1) into the original manuscript, "151" had become "51". It is quite possible that this error would have gone undetected and uncorrected had we not been

Caption for attached graphic:

Mathematicians often work with matrices, which are arrays of numbers. When written on a page, a matrix can look like a sea of numbers, so any patterns that might occur in the numbers can be difficult to discern. More and more, mathematicians are turning to graphical representations of matrices, like the two examples here. By using color and form to indicate the values of the numbers in the matrix, these graphical representations can instantly give a sense of the patterns in the matrix. The first picture is a representation of a matrix in which the numbers exhibit a clear pattern, the second picture, by contrast, is a matrix in which the numbers are random. (Graphic by David Bailey and Jonathan Borwein. Request their permission before reproducing the graphic.)



AMS Embargoed PR

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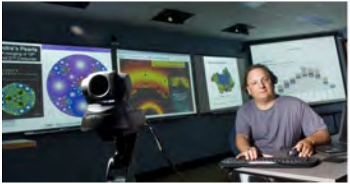
CARMA's Mandate

toc

Mathematics, as "the language of high technology" (Tom Brzustowski) which underpins all facets of modern life and current Information and Communication Technology (ICT), is ubiquitous. No other research centre exists focussing on the implications of developments in ICT, present and future, for the practice of research mathematics. CARMA fills this gap.



CARMA's Access Grid Room (2008)

Through exploitation and development of techniques and tools for computer-assisted discovery and disciplined data-mining including mathematical visualization.

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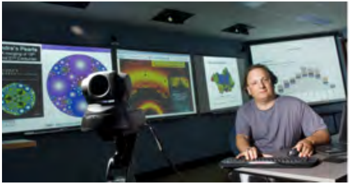

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CARMA's 2008 Objectives: largely met

To perform R&D relating to the informed use of computers as an adjunct to mathematical discovery (including current advances in cognitive science, in information technology, operations research and theoretical computer science)

– Of mathematics underlying computer-based support systems and to undertake mathematical modelling of such activities

– To promote and advise on use of appropriate tools (hardware, software, databases, learning object repositories, mathematical knowledge management, collaborative technology) in academia, education and industry [Global quick success, locally slower]

– To make University of Newcastle a world-leading institution for Computer Assisted Research Mathematics and its Applications[1]

[1]ERA: UofN only **2010** '5' in Appl. Maths & only real **2012** '5' (of 2) **2013** Top 200 Maths Dept (Shanghai) **2014** 3 FAA (9 at UofN)

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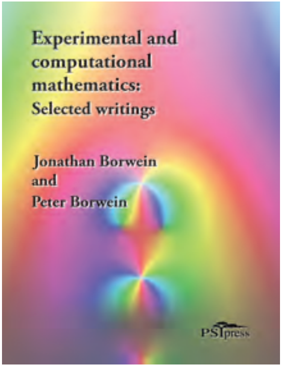
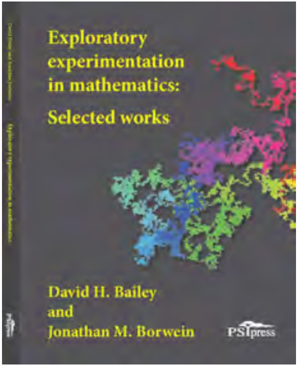
Communication and Computation: are entangled





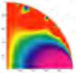
Communicating Mathematics (2008, 2010, 2012)

- 2012 *Science Communication* paper on AG seminars at http://www.carma.newcastle.edu.au/jon/c2c11.pdf

CARMA's 'Deep' History (Daniel Lord Smail)

A co-evolution of symbolic/numeric (hybrid) computation, experimental maths, collaborative technology and **HPC**.

Experimentally-found modular fractal took three hours to print in 2003



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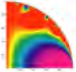

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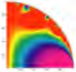

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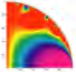

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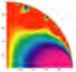

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CARMA's 'Deep' History (Daniel Lord Smail)

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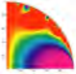

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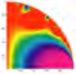

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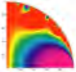

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Required:

- taking (reasonable) risks—intellectual and managerial
- (unreasonable) persistence—with senior administrators
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CARMA's Structure and Membership

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Currently **36** Members, 8 Associates, 7 Student Members:

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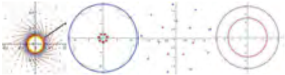

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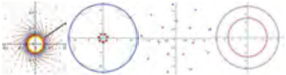

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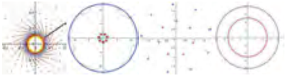

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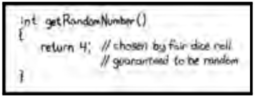

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HPC 104 core MacPro x-grid Cluster; 144-core HTCondor cluster (64 GB) (RedHat); 12-core (24 hyperthreaded) Linux server (192 GB RAM) + access to NSW/National compute services.

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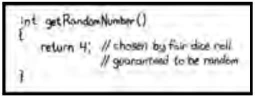

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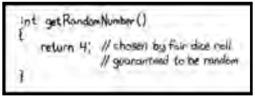

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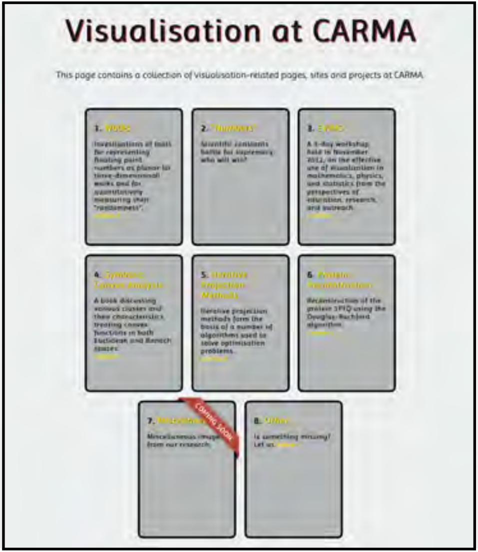

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2. Bookmark the Home page
3. Regularly monitor Events and make sure they are advertised
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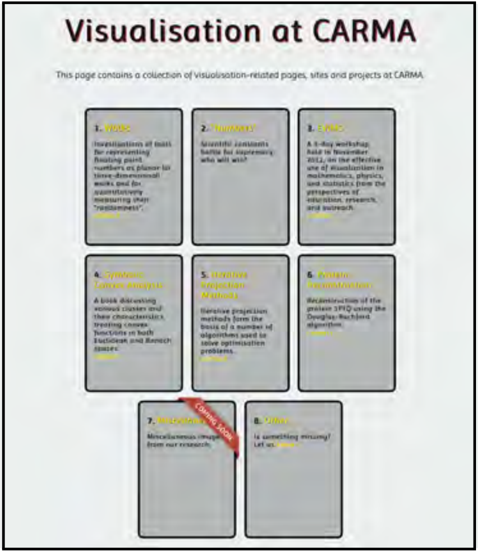

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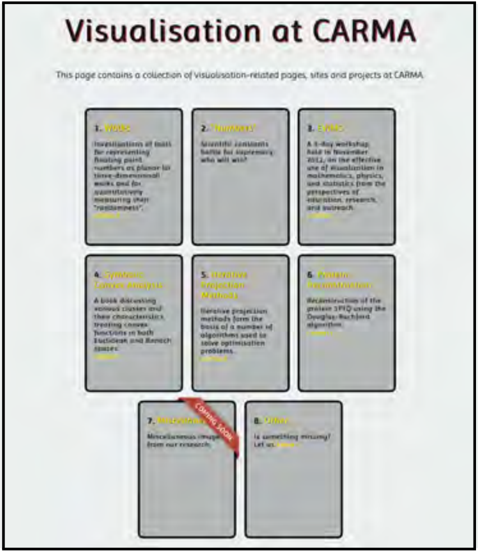

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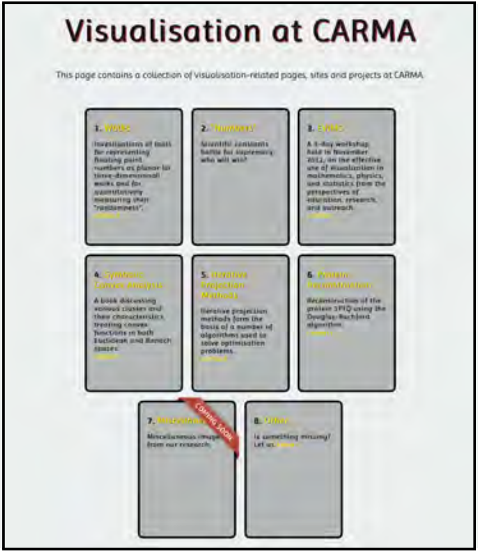

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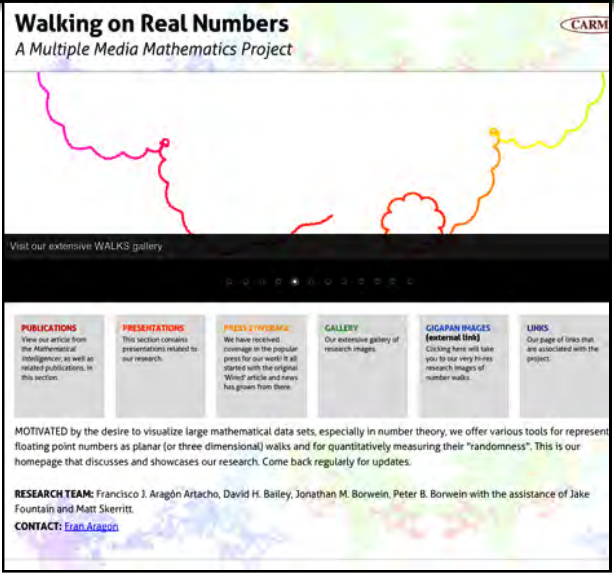

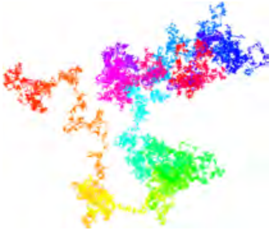

Turtle plots of π and paper-folding

See http://carma.newcastle.edu.au/walks/

Member Services

Allingham, Danson, & Turner

- We offer a variety of services to our members and their students (and to many others)
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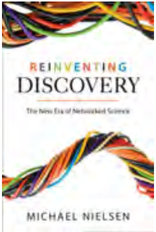

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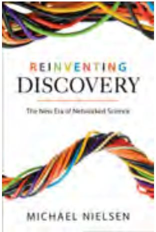

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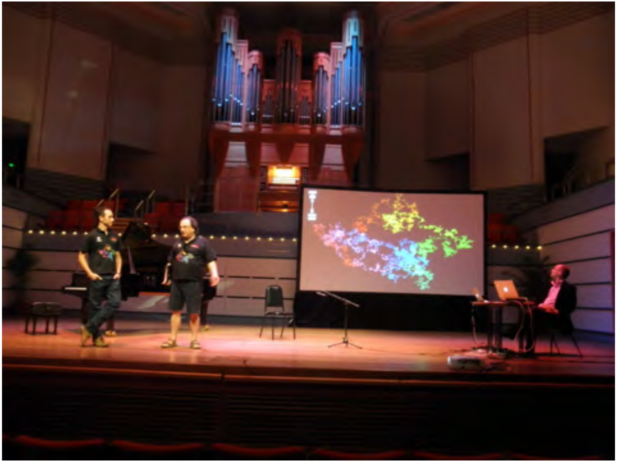
Non-traditional Publication

video and audio

Learn about Pi at http://www.carma.newcastle.edu.au/jon/piday-14.pdf



October 25 2012: Music and Maths Concert http://carma.newcastle.edu.au/pdf/music_maths.pdf

Hear Pi at http://carma.newcastle.edu.au/walks/

Conclusions

We are (mainly) having fun

- We are Pragmatic Dreamers
  - always aiming slightly too high
- The members' enthusiasm and work ethos is superb. We all *own* CARMA
- We cover all bases – research, applications, outreach and education
  - *We can not fund education. I am, however, strongly in favour of early introduction to research.*

    (Eliot Phillipson, former CFI and CIHR President)
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Not Bad for the First Five Years ... and we have big plans

Given *real* support from P/VC for:

- hiring next CARMA Director/HoS;
- to make Pure Maths an ERA '5'; Maths a top 100 department.

2010: Communication is not yet always perfect

Related Material

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2. Experimental Mathematics: for Everything
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3. Pi Day:
   http://carma.newcastle.edu.au/jon/piday.pdf
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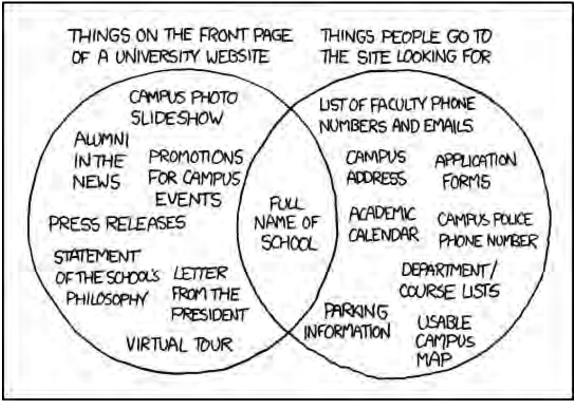
Building a new research centre ... is hard work



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But it *can* be very rewarding.

Thank you

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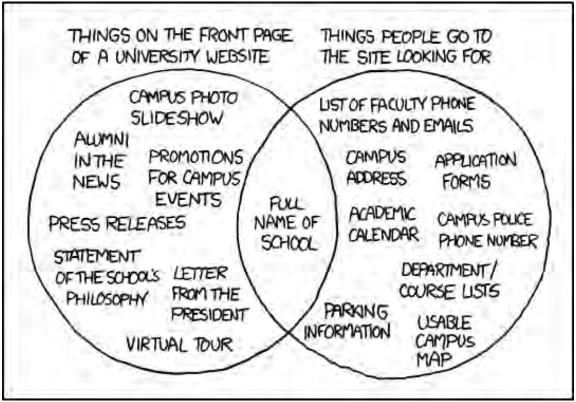

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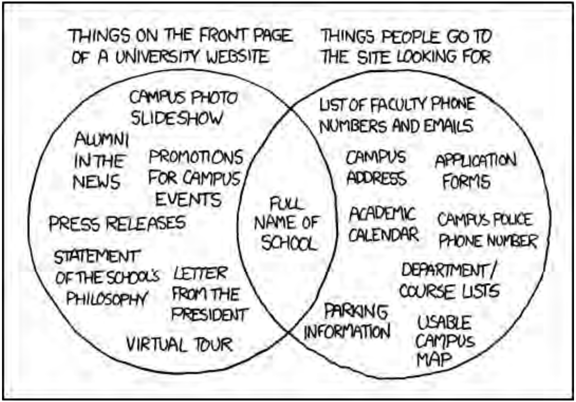

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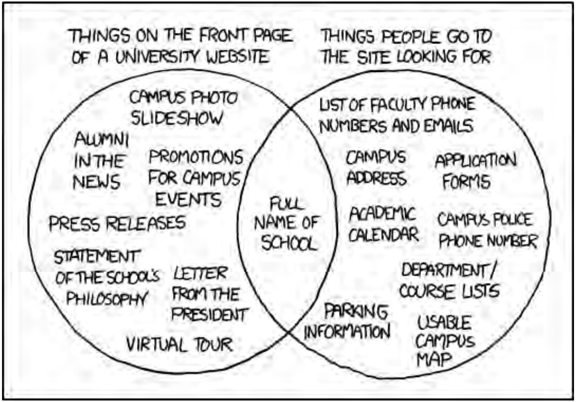
But it *can* be very rewarding.

Thank you

CARMA

Building a new research centre

... is hard work



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