

The “NASA Effect” of a Global Digital Math Library

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Big Proof 2019

International Centre for Mathematical Sciences

Edinburgh, 27-31 May 2019

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UNIVERSITY OF WATERLOO
FACULTY OF MATHEMATICS

Outline

- Personal Background
- Viewpoints
- Digital Math Libraries
- Flexibility
- IMKT
- The “NASA Effect”

Personal Background

- **Computer Algebra**

- As a user, creating Maple (1981), creating Axiom (1991)
- Symbolic algorithms and software systems (infinite structures, symbolic exponents, approximate polynomials, ...)

- **Programming Languages** for Symbolic Computation

- Aldor (1994), dependent types λC , optimizing compiler, algebra library

- Mathematical **Knowledge Management**

- TeX, MathML, OpenMath content conversion
- n -gram analysis, document classification

- Mathematical **Handwriting Recognition**

- Curve classification via LS, handwriting neatening
- Computer-aided collaboration

- Academic administration

- Waterloo has 8600 students taking math degrees

- **Not math formalization**, ATP, ITP

A Computer Algebra Viewpoint

- Programming, along with user errors.
- Keeping track of obligations, your responsibility.
- Division by zero, your fault.

- Primary job: Compute expressions for things we don't know.
Can verify by independent calculation, if necessary.

Computer Algebra Viewpoint

- Certain domains with solid theory treated with great care.
- Library built on polynomial algebra, linear algebra, differential algebra.
- In others, ignore theoretical impediments, e.g. simplification.
- User wants results, even if they are not universal or exhaustive.

THE JOURNAL OF SYMBOLIC LOGIC
Volume 33, Number 4, Dec. 1968

SOME UNDECIDABLE PROBLEMS INVOLVING ELEMENTARY FUNCTIONS OF A REAL VARIABLE

DANIEL RICHARDSON

Introduction. Let E be a set of expressions representing real, single valued, partially defined functions of one real variable. E^* will be the set of functions represented by expressions in E .

If A is an expression in E , $A(x)$ is the function denoted by A .

It is assumed that E^* contains the identity function and the rational numbers as constant functions and that E^* is closed under addition, subtraction, multiplication and composition. In every case it is also supposed that given A and B in E there is an effective procedure for finding expressions in E to represent

$$\begin{aligned} &A(x) + B(x), \\ &A(x) - B(x), \\ &A(x) \cdot B(x), \\ &A(B(x)). \end{aligned}$$

$A(x) \equiv B(x)$ will mean that $A(x)$ and $B(x)$ are defined at the same points and equal wherever they are defined.

The identity problem for (E, E^*) is the problem of deciding, given A in E , whether $A(x) \equiv 0$.

The integration problem for (E, E^*) is the problem of deciding, given A in E , whether there is a function $f(x)$ in E^* so that $f'(x) \equiv A(x)$.

Properties in Axiom (c. 1990s)

Ring: Category == Join(AbelianGroup, Monoid) with

Distributive(*, +)

Quaternion(R: Ring): Join(Ring, Module R) with

quaternion: (R, R, R, R) -> %

== add

Rep == Record(r: R, i: R, j: R, k: R)

(a: %) + (b: %) == [a.r + b.r, a.i + b.i, a.j+b.j, a.k+b.k]::%

-- Distributivity is not verified!

(a: %) * (b: %) == [a.r*b.r - a.i*b.i - a.j*b.j - a.k*b.k, a.r*b.i + a.i*b.r + a.j*b.k - a.k*b.j,
 a.r*b.j - a.i*b.k + a.j*b.r + a.k*b.i, a.r*b.k + a.i*b.j - a.j*b.i + a.k*b.r]::%

...

Number of Users

Excel :: Maple :: Lean

$O(10^9)$:: $O(10^7)$:: $O(10^3)$??

Document Point of View

- Metadata (Author, Title, Publication date, ...)
- Subject classification, keywords
- References

- Metadata validation
- Document analysis systems
- Collection management

Formalized Mathematics Point of View

- Formal definitions and claims
- Machine-verified proofs, all cases covered
- Examples:
 - Math libraries
 - 4 colour map theorem, Kepler conjecture, Feit-Thompson odd order

Mathematical Knowledge Management (MKM)

- Unification of these areas
- Conferences since 2001

- Advance state-of-art in each of these areas

- E.g. from computer algebra point of view
 - Help systems -- what can I do here?
 - Evidence-based simplification rules

Digital Math Libraries – Early Concept

- Digitize all past mathematical literature and link it together with the present literature
- Initiators included:
Bernd Wegner (ZentralblattMath),
Keith Dennis (MathSciNet),
Paul Ginsparg (arXiv), and others

15 Years Ago

Philippe Tondeur – 1999-2002 [Director of Division of Mathematical Sciences](#)
[US National Science Foundation](#)

WDML: THE WORLD DIGITAL MATHEMATICS LIBRARY

**The Evolution of Mathematical Communication in the Age of
Digital Libraries**

IMA Workshop, December 8-9, 2006

Philippe Tondeur

Professor of Mathematics

University of Illinois at Urbana-Champaign

15 Years Ago

Philippe Tondeur – 1999-2002 [Director of Division of Mathematical Sciences](#)
[US National Science Foundation](#)

The MATH INVENTORY

- 2,300 journals and periodical publications
- 2,000,000 items identified since 1868
- 80,000 additional items per year
(in comparison: 1,500 additional monographs per year)

What the Future Was

- A linked repository of articles is nice, but don't we have this already?



A Modern View

- Semantic capture
- Machine-accessible knowledge base
- Natural language queries
- Personalized learning
- Historical perspectives
- Conjecture generation

A Modern View

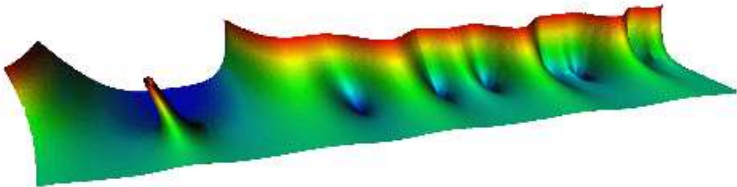
DLMF: NIST Digital Library of Ma x +
https://dlmf.nist.gov

*D*igital
*L*ibrary of
*M*athematical
*F*unctions

Index
Notations

Search
Help?
Citing
Customize

About the Project
NIST
National Institute of
Standards and Technology
U.S. Department of Commerce



NIST Digital Library of Mathematical Functions

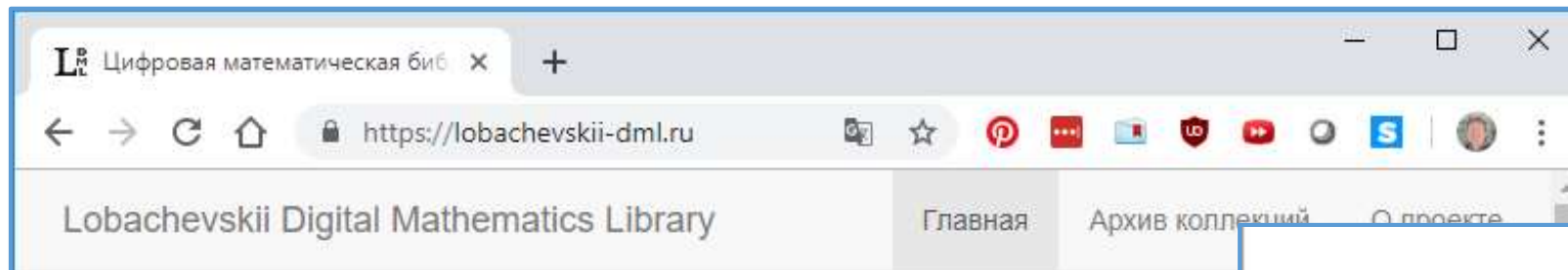
Project News

- 2019-03-15 [DLMF Update: Version 1.0.22](#)
- 2018-12-15 [DLMF Update: Version 1.0.21](#)
- 2018-09-15 [DLMF Update: Version 1.0.20](#)
- 2018-06-22 [DLMF Update: Version 1.0.19](#)

[More news](#)

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8 Incomplete Gamma and Related Functions	30 Spheroidal Wave Functions
	31 Heun Functions
	32 Painlevé Transcendents

International



Цифровая математическая библиотека Лобачевского

Цифровая математическая библиотека, построенная по принципу управления объектами математического знания, а не математическими документами. Основу заложен фундаментальный принцип создания сети математической информации, которая основана на знаниях, содержащихся в публикациях, представленных в электронных коллекциях.

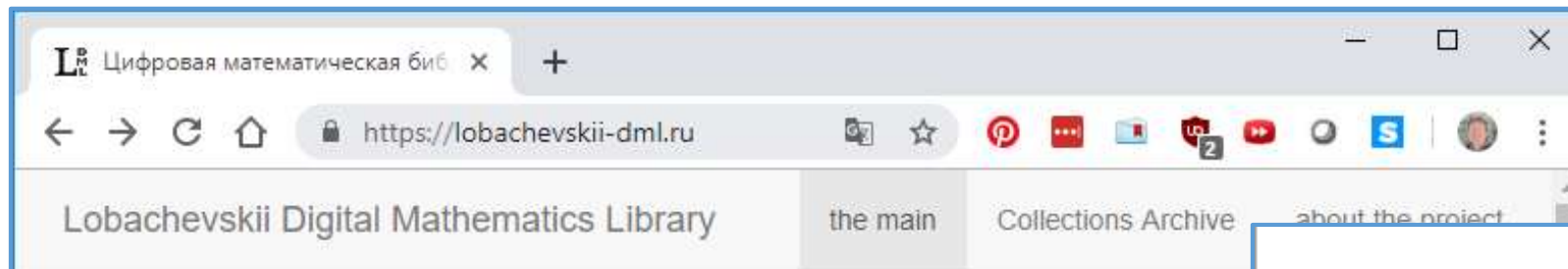
WDMLプロジェクトの解説

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2005年9月21日(水)

日本の数学文献の電子化について

International



Lobachevsky Digital Mathematics Library

Digital Mathematical Library, built on the principle of managing objects of mathematical knowledge, mathematical documents. It is based on the first principle of WDML - the principle of creating a mathematical information, which is based on the information contained in publications presented in electronic form.

Explanation of the WDML Project

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Lobachevskii DML collection

1998–2007 LJM electronic collection with semantic navigation tools. System of links with the LJM collection.

Lobachevskii DML services

When designing the digital library Lobachevskii-DML, we used previously obtained results on the

Wed, Sept 21, 2005

Computerization of Japanese math literature

Capturing Math

PDF page images

vs

Expression OCR

vs

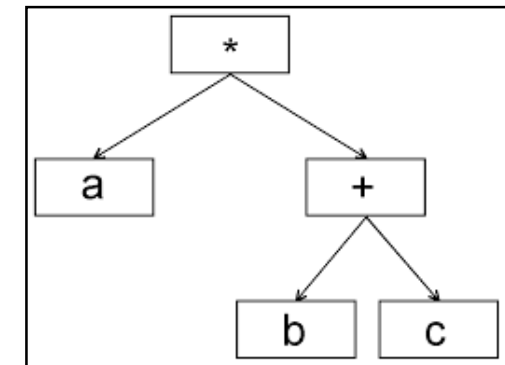
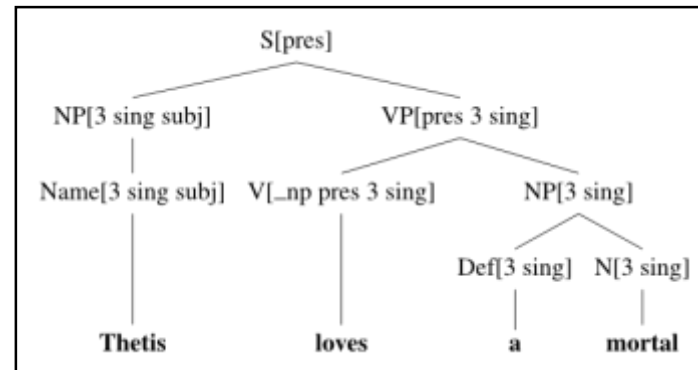
Natural language statements

vs

Formalized mathematics

Capturing Math

- Page images *or* born-digital pages
- Structure analysis (DAS)
- Natural language and math recognition (e.g. FK, MG)
- Identification of glyphs.
- Parsing
- Semantic capture



Semantic Capture

- Extract the mathematical content of the paper.
- Can mean many things:
 - Statement of main definitions and main results.
 - Links to relevant literature.
 - Proof of results
(at the level of formality in the paper or completely formal)
 - Discourse

Semantic Capture

- rich: allow all kind of mathematical statements
- flexible: allow human and computational annotation
- trust in the future: first instances can cost much more than subsequent
 - Increased automation, better sw + hw infrastructure
- future-proof: allow enhanced processing and annotation over time
- allow different "levels" of annotation

Different Meanings for Basic Concepts

- 1391 Chaucer: "Equation"
- 1557 Recorde: "="
- 1637 Descartes: "x"

1. $x^4 - a = 0$

2. $xa = ax$

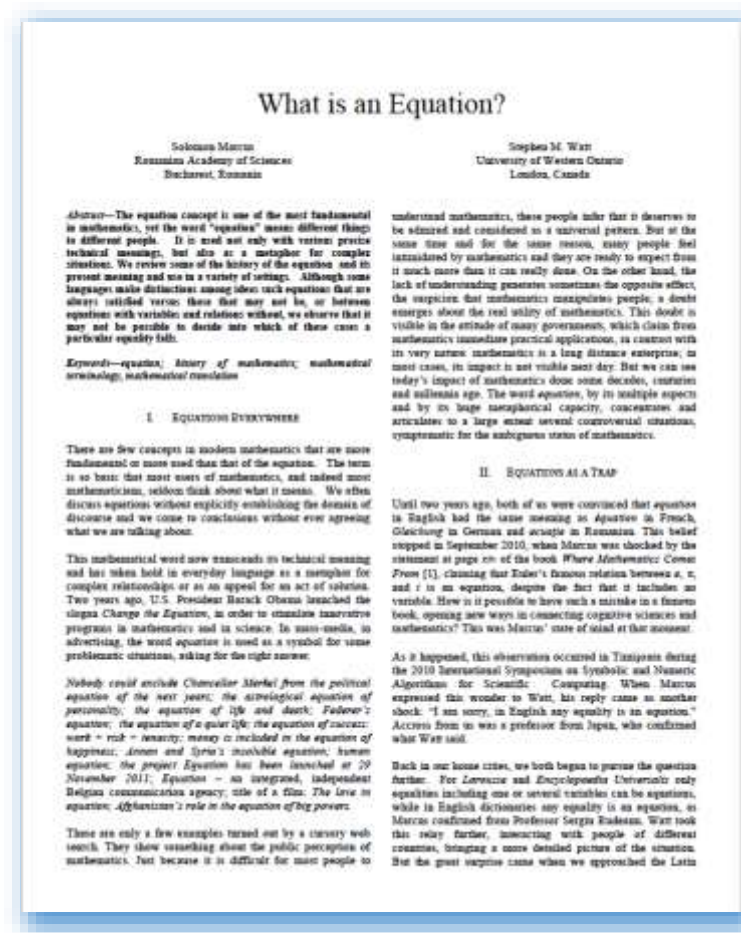
3. $8 + 2 = 10$

A. 1,2,3 "equation"

B. 1 "équation", 2 "identité", 3"rélation"

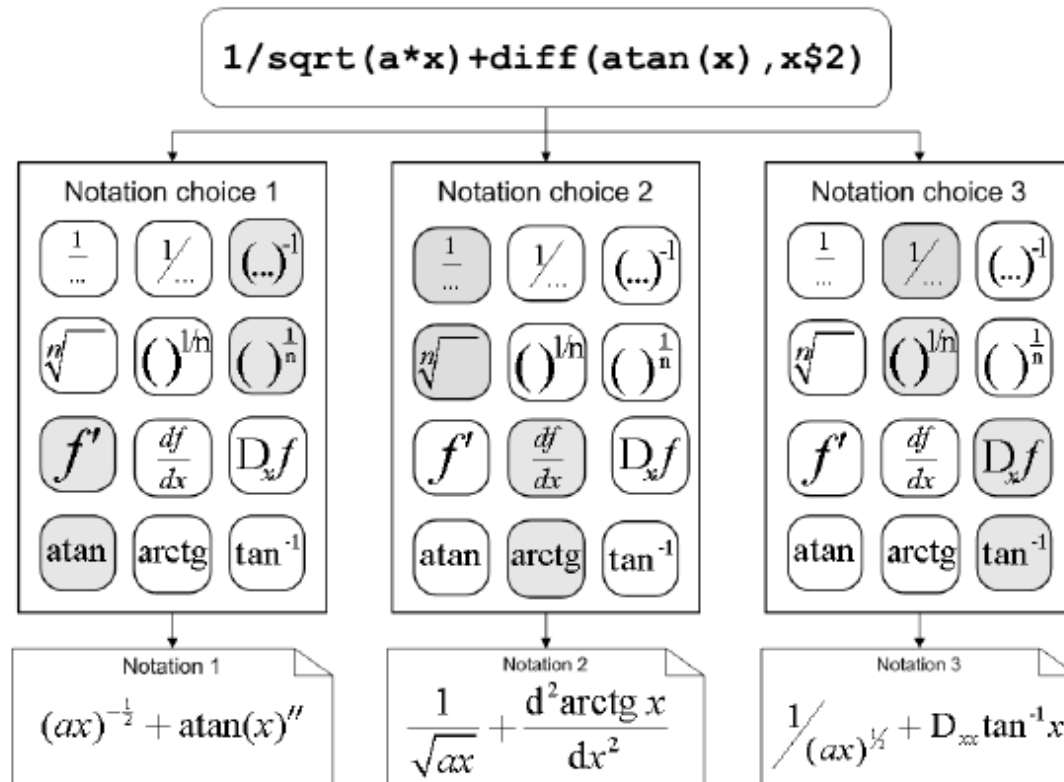
- English, Latin A
- Chinese, French, German, Russian,... B

- 1 vs 2 undecidable



Different Notations for the Same Thing

- TeX \leftrightarrow MathML, Presentation \leftrightarrow Content



Different Things for the Same Notation

- J_ν
 - Bessel function
 - Angular momentum
 - 4-current

“According to Abramowitz and Stegun”
or arccoth needn't be uncouth

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Abstract

This paper¹ addresses the definitions in OpenMath of the elementary functions. The original OpenMath definitions, like most other sources, simply cite [2] as the definition. We show that this is not adequate, and propose precise definitions, and explore the relationships between these definitions.

In particular, we introduce the concept of a couth pair of definitions, e.g. of arcsin and arcsinh, and show that the pair arccot and *arccoth* can be couth.

1 Introduction

Definitions of the elementary functions are given in many

functions, as well as relations between these functions, and relations between them and the forward functions.

We discuss the implications of accurate translation on the design of the phrasebooks [5] translating between OpenMath and actual systems. Note that OpenMath does not say that one definition is ‘right’ and another ‘wrong’: it merely provides a *lingua franca* for passing semantically accurate representations between systems. Semantically correct phrasebooks would deduce that

$$\underbrace{\text{arccot}}_{\text{Maple}} z = \frac{\pi}{2} - \underbrace{\overline{\text{arctan}}}_{\text{Derive}} \bar{z}.$$

Notation. Throughout this paper, we use arccot etc to mean the precise function definitions we are using, and vari-

Informal vs Formal Mathematics and DMLs

Example: Derivation of the Dirac equation.

$$E^2 - p^2 = m^2$$

$$p^\mu p_\mu - m^2 = (\beta^k p_k + m)(\gamma^\ell p_\ell - m)$$

$$= \beta^k \gamma^\ell p_k p_\ell - m^2 + m \gamma^\ell p_\ell - m \beta^k p_k$$

$$= 0 \quad \Rightarrow \quad \beta^k = \gamma^k, \quad \gamma^i \gamma^j + \gamma^j \gamma^i = 2g^{ij}$$

$$(i\gamma^\mu \partial_\mu - m)\psi = 0$$

Informal vs Formal Mathematics and DMLs

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$$(i\gamma^\mu \partial_\mu - m)\psi = 0$$

$$\gamma^0 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad \gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ -\sigma^\mu & 0 \end{pmatrix} \quad \sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix} \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Different Levels of Formalism

- Exist in the literature
- "Flexi-formalism" (Kohlhase)
- The de Bruijn factor (Freek): ~ 4
- "A little inaccuracy saves a world of explanation."



Clovis on the Alleged Romance of Business

1924

“IT is the fashion nowadays,” said Clovis, “to talk about the romance of Business. There isn’t such a thing.

. . .

It was the unledgered wanderer, the careless-hearted seafarer, the aimless outcast, who opened up new trade routes, tapped new markets, brought home samples or cargoes of new edibles and unknown condiments. It was they who brought the glamour and romance to the threshold of business life, where it was promptly reduced to pounds, shillings, and pence ; invoiced, double-entried, quoted, written-off, and so forth ; most of those terms are probably wrong, but a little inaccuracy sometimes saves tons of explanation.

. . .

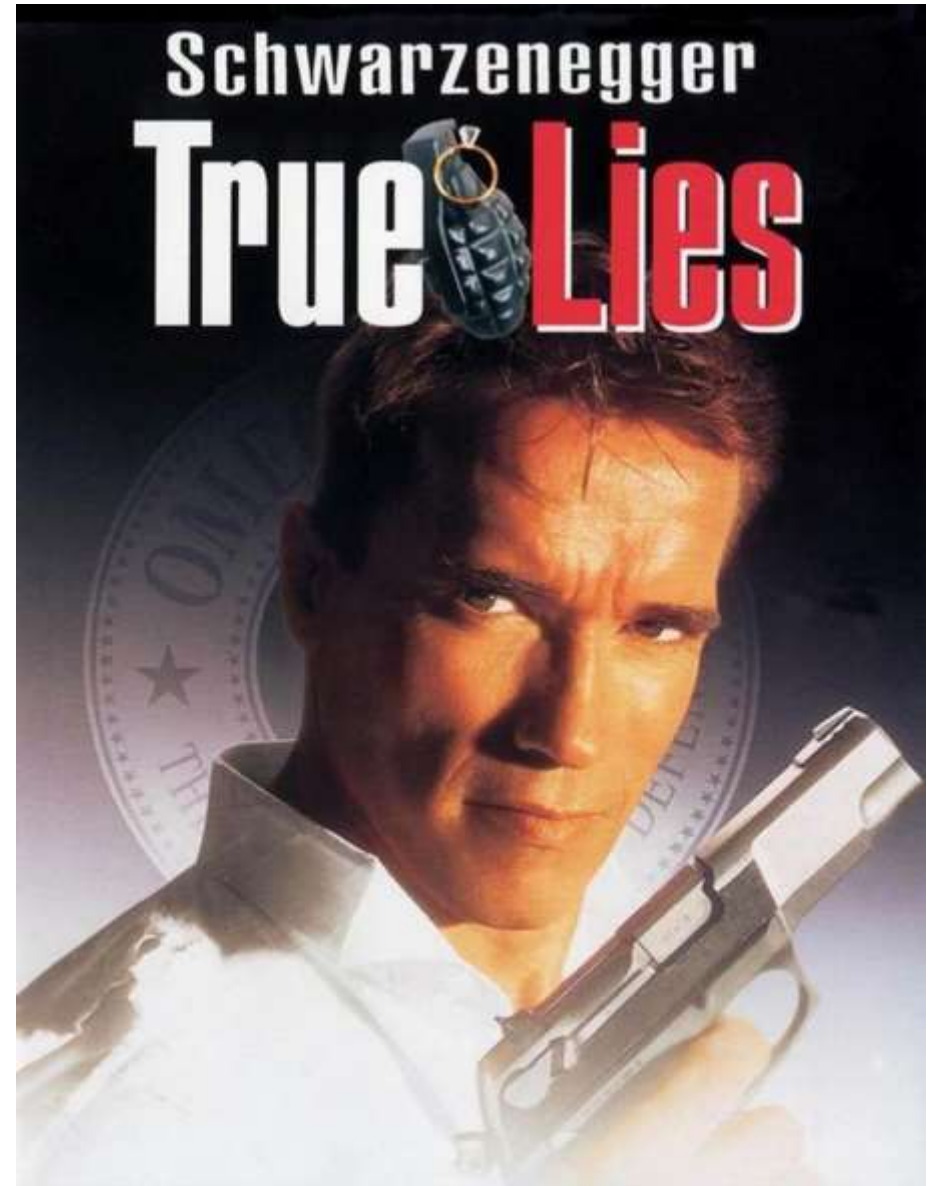
Whenever I feel in the least tempted to be business-like or methodical or even decently industrious I go to Kensal Green and look at the graves of those who died in business.”



H. H. Munro ("Saki")
1870-1916
E. O Hoppé

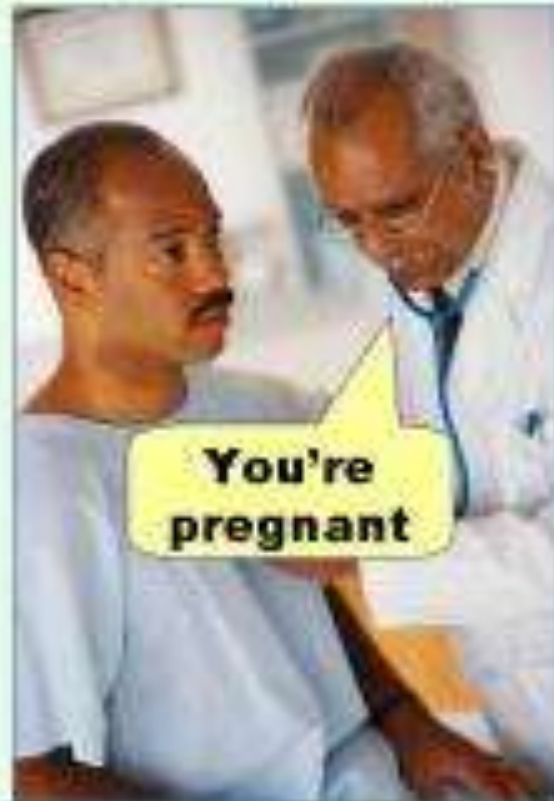
Discussion about Math

- True statements about false things.
- False statements about true things.



Errors

Type I error
(false positive)



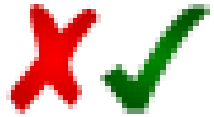
Type II error
(false negative)



Types of Errors (Math Overflow)

- ✓ Result is correct and was later rigorously proved.
- ✗✓ Result is wrong as stated, but a modified version was later rigorously proven.
- ? Status of the result is unclear
- ✗? Result is wrong as stated, but a modified version was suggested whose status is unclear.
- ✗ Result is wrong

Examples of Errors (Math Overflow)



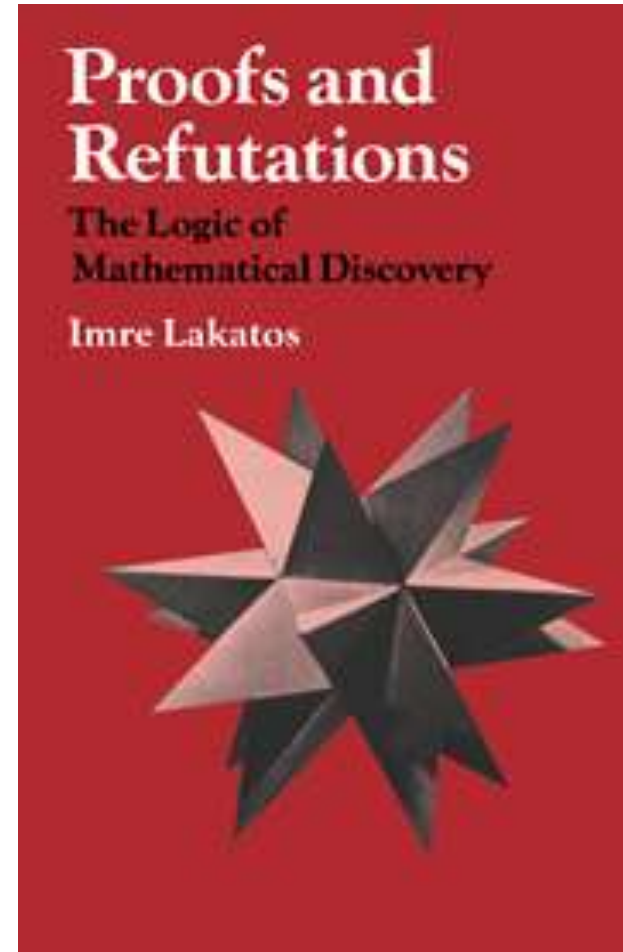
- Dirichlet's Principle
- Federov's class'n of convex polyhedra
- Mansion's Wronskians
- Plemelj & Hilbert's 21st problem
- Grunwald-Wang theorem



- Ampère differentiability of continuous fns
- Frege Begriffsschrift consistency
- Severi finite dim space of rat equiv classes
- Vahlen's example of 3-d algeb curve

On Being Wrong

- Sometimes correct new mathematics is built on unjustified, but correct claims.
- Sometimes refutation of incorrect claims leads to important new mathematics.
- A DML must be able to represent and discuss incorrect claims.



Hybrid Libraries

- Safe modules relying on unsafe code

Some capability is deemed unsafe, where the compiler can no longer guarantee the results will be consistent (for example, when interfacing to the C programming language). The keyword `UNSAFE` prefixed in front of `INTERFACE` or `MODULE`, may be used to tell the compiler to enable certain low level features of the language. For example, an unsafe operation is bypassing the type system using `LOOPHOLE` to copy the bits of an integer into a floating point `REAL` number.



An interface that imports an unsafe module must itself be unsafe. A safe interface may be exported by an unsafe implementation module. This is the typical usage when interfacing to external libraries, where two interfaces are built (one unsafe, the other safe).




5 Years Ago

Ingrid Daubechies – 2011-2014 [President of the International Mathematical Union](#)

Next steps towards a Global Mathematics Library 2014 x

 **Ingrid Daubechies** ingrid@math.duke.edu via [uwo.ca](#) 7/23/14 

to watt, m.kohlhase, sojka, Vladimir, pitman, bruno.buchberg., Peter.Paule, Jeb 

Dear Colleague,

This is an invitation to attend a 2-hour meeting to discuss development of a Global Digital Mathematics Library (GDML). This meeting will be held during and at the same venue as the upcoming International Congress of Mathematicians (ICM) of the International Mathematical Union (IMU); more precisely, it will take place in the afternoon of August 17, 2014, in or near the COEX Conference Center in Seoul, S. Korea. Exact details will be communicated later, and will depend, in part, on the number of people who can attend in person or remotely, and the times convenient to them.

This proposed meeting is organized by the Committee on Electronic Information and Communication (CEIC) of the IMU. It is in response to the report by the National Academy of Sciences of the USA (available from <http://arxiv.org/abs/1404.1905> or http://www.nap.edu/catalog.php?record_id=18619) -- and, in particular, the section "Constitution of the Digital Mathematics Library Organization" starting on page 80.

5 Years Ago

Ingrid Daubechies – 2011-2014 [President of the International Mathematical Union](#)

The meeting's goal is to assess interest of organizations and individuals in contributing to this effort and to discuss setting up a small organization that would

- * coordinate efforts of several existing DML efforts, some started after the IMU's call for a World Digital Mathematics Library (WDML) several years ago;
- * encourage the development of tools and a platform that would add functionality to these DMLs beyond the simple availability of documents, and that would be useful to mathematical researchers worldwide;
- * help build a consortium of institutions to support the GDML.

5 Years Ago

- **IMU Working Group established to**
 - Develop a concrete roadmap
 - Incremental budget
 - Organize proposals to funders
- **Members:**
 - Thierry Bouche (EuDML)
 - Bruno Buchberger (Risc LINZ)
 - Patrick Ion (Math Reviews (ret.), MathML)
 - Michel Kohlhase (Jacobs, OpenMath)
 - Jim Pitman (Berkeley)
 - Olaf Teschke (ZbMath)
 - Stephen Watt* (ORCCA, MathML, doc analysis)
 - Eric Weisstein (MathWorld, Wolfram Research)



WG Activities

- Workshops, sessions and panels
- Specific presentations and conference presentations
- Seed funding grant
- Founding not-for-profit
- Seed projects

International Mathematical Knowledge Trust

The background of the slide is a complex, abstract fractal pattern. It features a central, bright golden-yellow flower-like structure that spirals outwards, surrounded by numerous overlapping, semi-transparent layers of orange and brown. The overall effect is a sense of depth and mathematical complexity, with light reflecting off the various surfaces of the fractal.

The International Mathematical Knowledge Trust (IMKT) has as its long-term goal the creation of a comprehensive mathematical knowledge base, to be used by people and software systems world-wide. The IMKT supports a variety of digitization and mechanization projects for mathematical data and knowledge. These efforts are coordinated with a number of commercial and not-for-profit partners, consistent with a commitment to Open Data.



Governance

The IMKT was first set up as a step on the path to a global digital mathematics library, as that may be understood in the present day, with a grant from the Alfred P. Sloan Foundation to principal investigators associated with the Global Digital Mathematics Library Working Group of the International Mathematical Union's Committee on Electronic Information and Communication under its 2015 remit.

[MORE](#)

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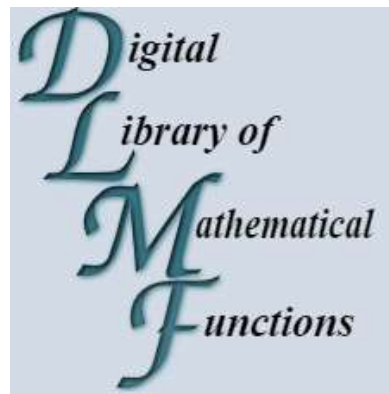


Events

- Mathematical Information in the Digital Age of Science, JMM 2016
- Semantic Representation of Mathematical Knowledge, Fields Institute, 2016
- 10th Conference on Intelligent Computer Mathematics, 2017
- Applications of Computer Algebra, 2017
- Mathematical Information in the Digital Age of Science, JMM 2018
- Computer Aided Mathematical Proof, INI, 2017
- ICM, 2018
- Big Proof 2019

IMKT Initial Objectives

- F Abstracts
- Formal Harmony
- Special Function Concordance
- Mathematical Document Classification (N-Grams and Machine Learning)



NIST



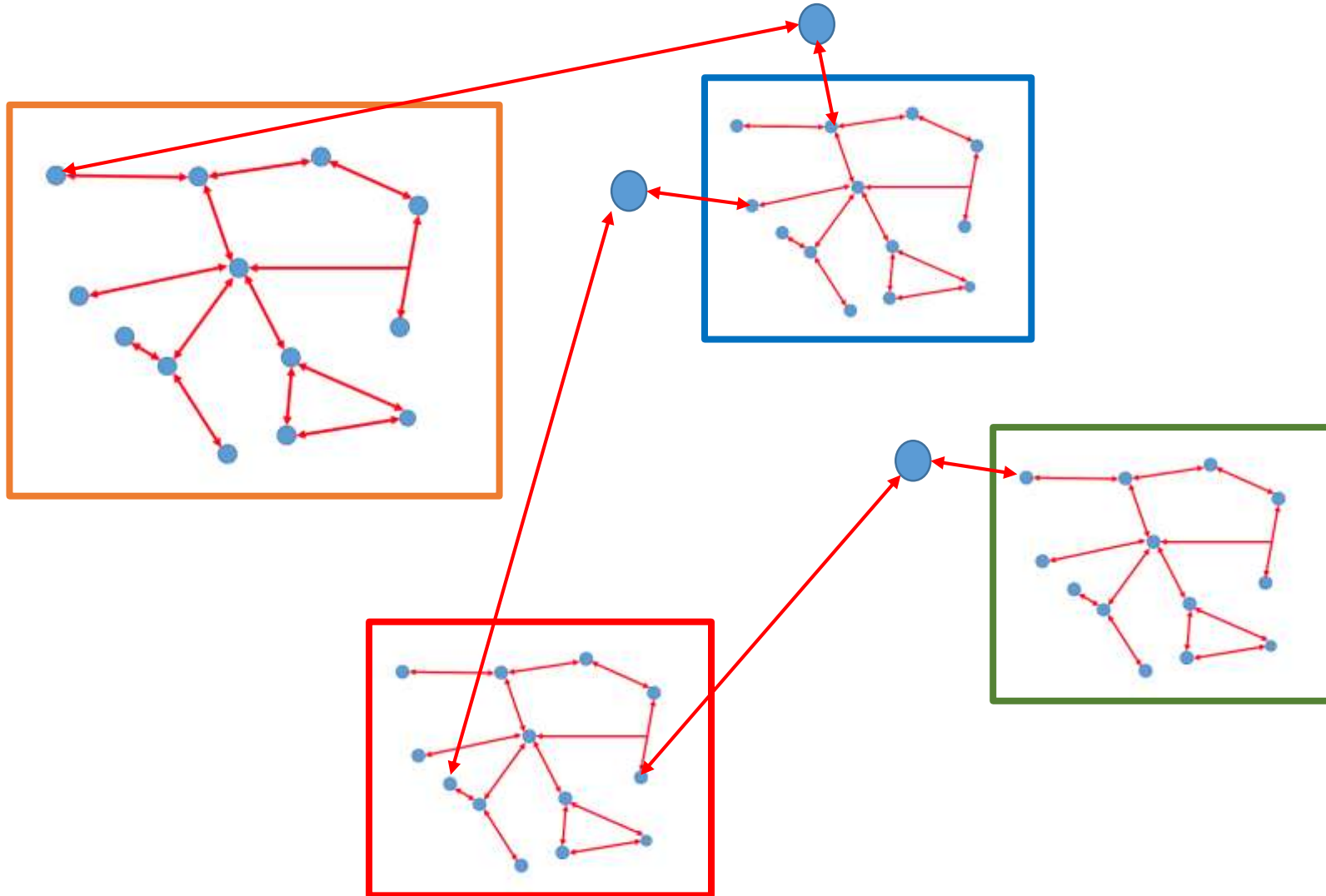
Tom Hales



Gilles Dowek



Several Groups' Work



Slightly Less Obvious Statements about Getting Something Done

- Can afford to hand-annotate/capture a small subset
- Rely on improvements of technology/AI
 - By Hand
 - Supervised automation
 - Automation + checking
 - Automation 😊?
- Approximation goes a long way
- Future-proof the data

The “NASA Effect”

- 1957 Sputnik
- 1958 NASA
- 1962 “We choose to go to the Moon”
- Pushback: “Costs too much”, “Money better spent”, ...
- 1969 Apollo 11 Moon landing

- 1979: Majority of Americans felt Apollo program did not justify costs
- 1999: Majority felt it did

<https://news.gallup.com/poll/3712/landing-man-moon-publics-view.aspx>

The “NASA Effect”

Claimed benefits:

- Increased public engagement in science
- Technological advance (remote sensing, sea floor mapping, electronics)
- Spin-offs
- Political benefit

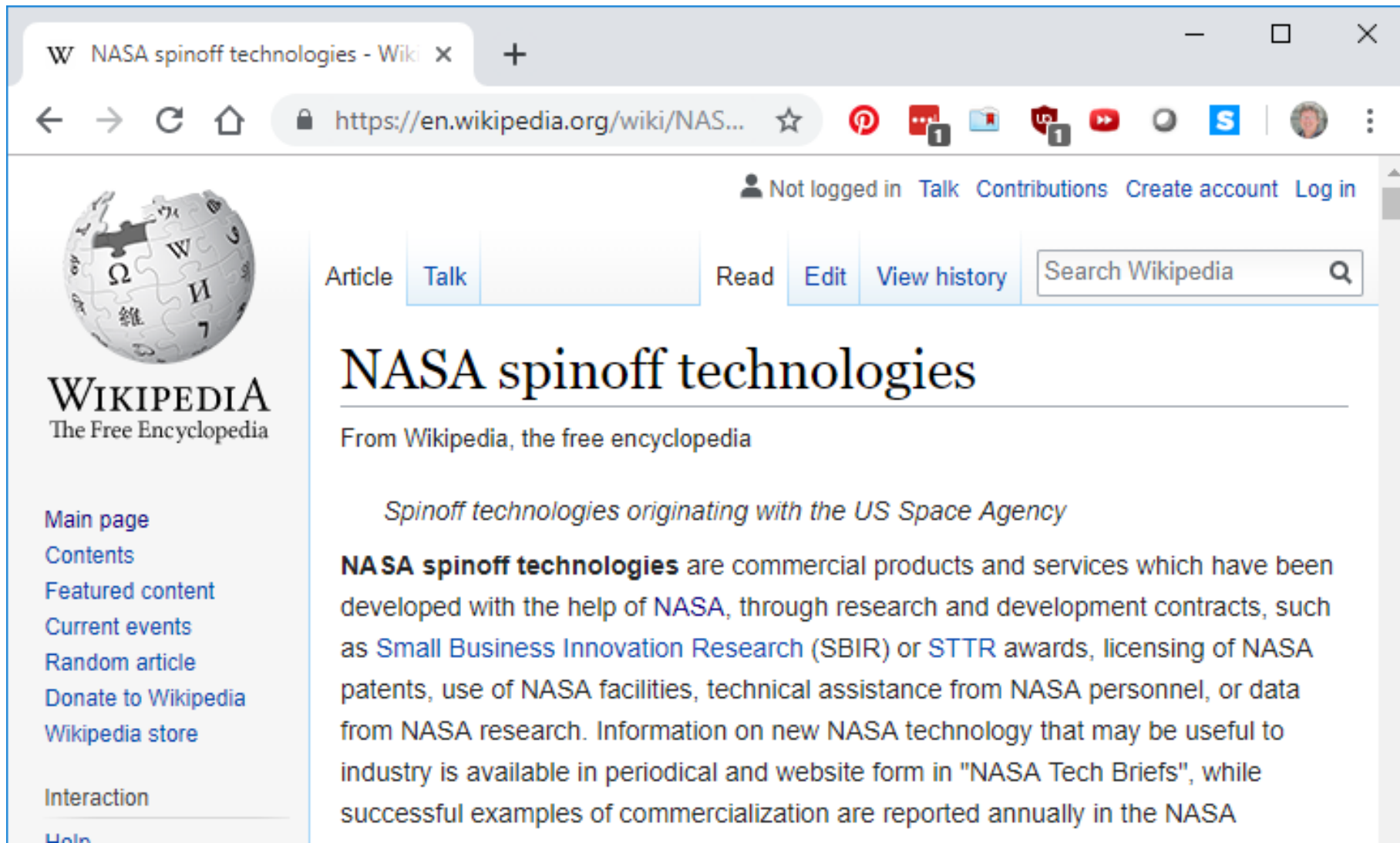
https://www.nasa.gov/centers/goddard/news/series/moon/first_lunar_program.html

- Sakharov’s open letter about democracy

The “NASA Effect”

- Making America cleverer: Intake of physics PhDs 3x
- In-flight computers, integrated circuits, Fairchild, Intel
- Surrey Satellite Technology Limited (Sweeting)
- Students for Exploration and Development of Space, Bezos president 1 yr
- Jobs

The “NASA Effect”



The image is a screenshot of a web browser displaying the Wikipedia article for "NASA spinoff technologies". The browser's address bar shows the URL "https://en.wikipedia.org/wiki/NAS...". The page header includes navigation links for "Not logged in", "Talk", "Contributions", "Create account", and "Log in". Below the header, there are tabs for "Article" and "Talk", and buttons for "Read", "Edit", and "View history". A search bar is also present. The main content area features the Wikipedia logo (a globe made of puzzle pieces) and the text "WIKIPEDIA The Free Encyclopedia". The article title "NASA spinoff technologies" is prominently displayed, followed by the subtitle "From Wikipedia, the free encyclopedia". The introductory paragraph reads: "Spinoff technologies originating with the US Space Agency". The main body of the article begins with the sentence: "NASA spinoff technologies are commercial products and services which have been developed with the help of NASA, through research and development contracts, such as Small Business Innovation Research (SBIR) or STTR awards, licensing of NASA patents, use of NASA facilities, technical assistance from NASA personnel, or data from NASA research. Information on new NASA technology that may be useful to industry is available in periodical and website form in 'NASA Tech Briefs', while successful examples of commercialization are reported annually in the NASA".

The “NASA Effect”

https://en.wikipedia.org/wiki/NASA_spinoff_technologies

1 History of the *Spinoff* publication

2 Health and medicine

- 2.1 Infrared ear thermometers
- 2.2 Ventricular assist device
- 2.3 LASIK
- 2.4 Artificial limbs
- 2.5 Light-emitting diodes in medical therapies
- 2.6 Invisible braces
- 2.7 Scratch-resistant lenses
- 2.8 Space blanket
- 2.9 [3D foods printing](#)

3 Transportation

- 3.1 Aircraft anti-icing systems
- 3.2 Highway safety
- 3.3 Improved radial tires
- 3.4 Chemical detection

4 Public safety

- 4.1 Video enhancing and analysis systems
- 4.2 Landmine Removal
- 4.3 Fire-resistant reinforcement
- 4.4 Firefighting equipment
- 4.5 Shock Absorbers for buildings

5 Consumer, home, and recreation

- 5.1 Temper foam
- 5.2 Enriched baby food
- 5.3 Portable cordless vacuums
- 5.4 Freeze drying
- 5.5 Space age swimsuit
- 5.6 Digital image sensor
- 5.7 Air-scrubbers

6 Environmental and agricultural resources

- 6.1 Water purification
- 6.2 Solar Cells
- 6.3 Pollution remediation
- 6.4 Correcting for GPS signal errors
- 6.5 Water location

7 Computer technology

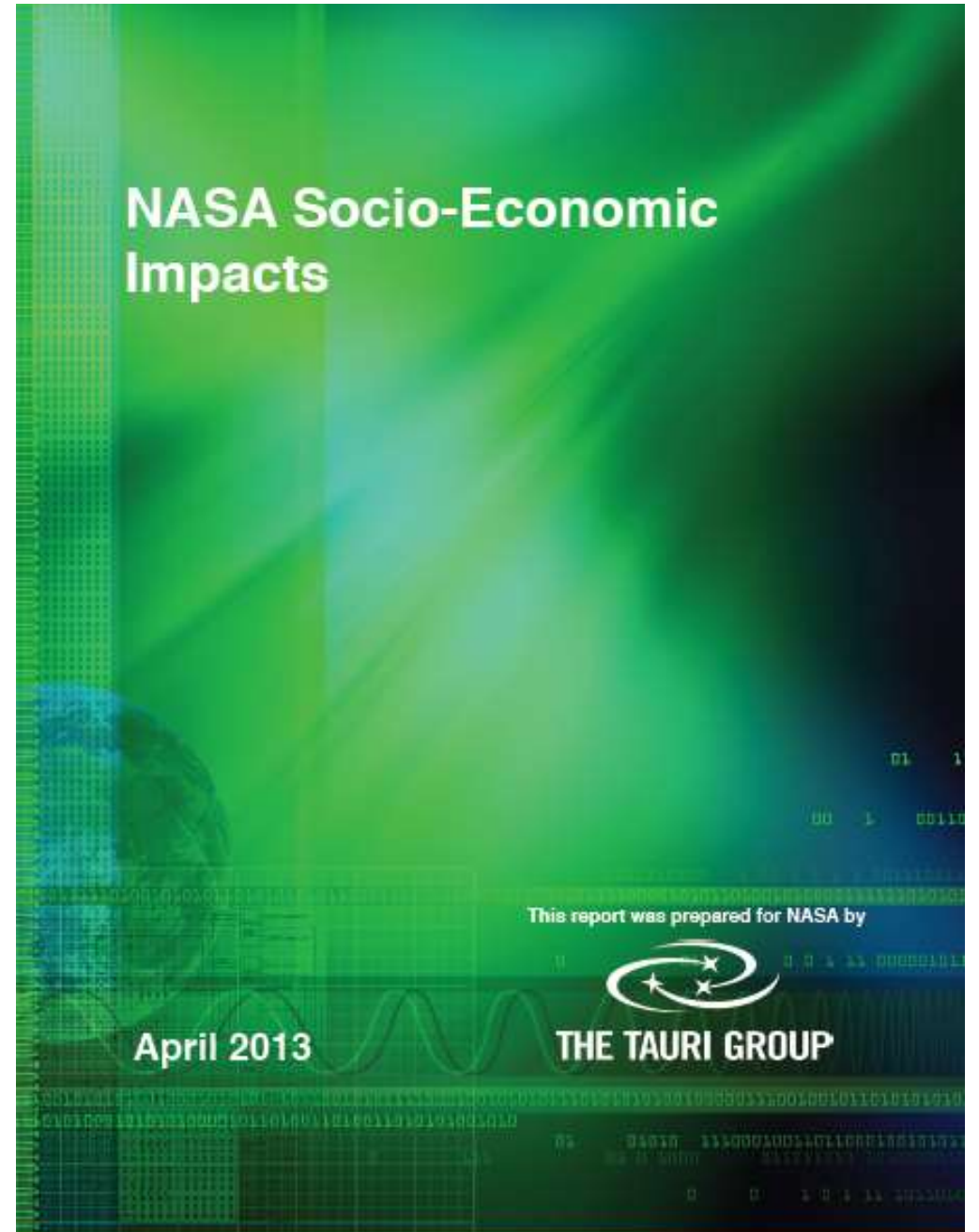
- 7.1 Structural analysis software
- 7.2 Remotely controlled ovens
- 7.3 NASA Visualization Explorer
- 7.4 OpenStack
- 7.5 Software catalog

8 Industrial productivity

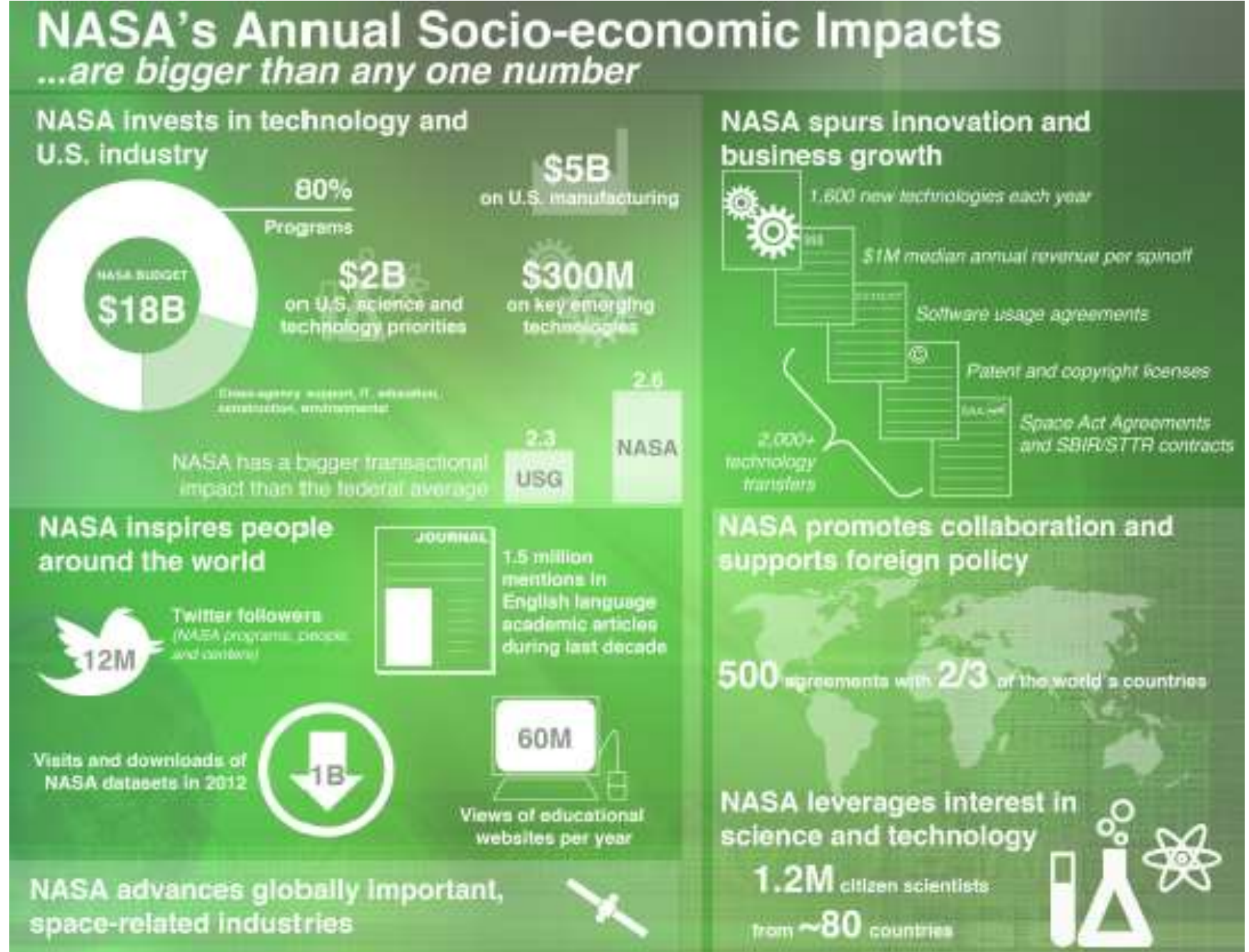
- 8.1 Powdered lubricants
- 8.2 Improved mine safety
- 8.3 Food safety

Not Tang, Velcro or Teflon

The “NASA Effect”



The “NASA Effect”



Perspective

15% OF ALL INTERNET TRAFFIC IS CAT-RELATED



Ensuring Mutual Intelligibility



Ptolemaic vs Copernican Architecture



en.wikiquote.org



gocomics.com

Esperanto vs Francophonie

