

**Report Type:** Renewal Application

**Reporting Year:** 2021

## General Information

**Name of the Centre/Institute:** Centre for Experimental and Constructive Mathematics

**Website:** <http://www.cecm.sfu.ca>

**Faculty:** Science

**Director:** Michael Monagan

**Director's term end:** 2021-04-01

**Renewal date:** 2021-04-01

## Details

### Description of the Centre/Institute:

CECM stands for the Centre for Experimental and Constructive Mathematics. CECM's mandate is to explore and promote the interplay of conventional mathematics with modern computation in the mathematical sciences and to support the creation and application of software that is designed for doing mathematics.

Members of the CECM work in a variety of areas in the mathematical sciences, including algebraic geometry, number theory, coding theory, computational algebra, cryptography, algebraic combinatorics, graph theory, and scientific computing. What brings us together is our common interest in mathematical software packages such as Maple, SageMath, Magma, Matlab and Macaulay2 which we use for all kinds of applications including searches, exploration, and verification of results. Together the members of the CECM possess a knowledge of mathematical software packages unmatched nationally.

The word "Experimental" in the title of the Centre refers to a new way of building conjectures in mathematics and searching for mathematical objects using the power of computers. While numerical experimentation has been integral to mathematics and dates back to at least Gauss, the computer has created the possibility of conducting mathematics as a lab science, with the computer as the lab and measuring instrument. Examples of this by CECM members include Jonathan Jedwab who uses the CECM computers to search for new Golay sequences in order to better understand their structure, Petr Lisonek who uses the CECM computers to search for quantum error control codes and highly nonlinear functions in cryptography, and Nils Bruin who uses the CECM computers for testing and adjusting conjectures in arithmetic geometry concerning the behaviour of 2-Selmer groups of Jacobians of non-hyperelliptic curves.

The word "Constructive" in the title indicates that we want to find explicit examples (codes, polynomials, matrices, graphs) and not just prove their existence. Indeed the computer has revolutionized the way many mathematicians conduct their research. Naturally we write

programs and develop software packages for doing mathematics. For example, Nathan Ilten has written and continues to actively develop the Macaulay2 package "VersalDeformations" and, Luis Goddyn and Michael Monagan and their students designed and programmed Maple's "GraphTheory" package.

Members of the CECM generally belong to four research groups in the department, three of which were founded by members of the Centre. The four research groups are the Computer Algebra Group, the Discrete Mathematics Group, the Arithmetic/Algebraic Geometry Group and the Number Theory Group. A focal point of each group is a weekly or biweekly seminar where research is presented by faculty, students and visitors. Each group maintains a web page with a record of the seminars and other activities. Links to the group web pages can be accessed from the main CECM webpage at [www.cecm.sfu.ca](http://www.cecm.sfu.ca).

Another key way the CECM supports members is by providing a physical lab space for faculty, students and visitors to work in. This CECM lab P8495 has desks for 20 people, each with a desktop computer; a small lounge which is where we often meet to work; a small office suitable for one postdoc or visitor; and a machine room which has a file server, web server, and four multi-core compute servers which run the mathematical software packages Maple, SageMath, Magma, Matlab and Macaulay2. We have been blessed with a great lab and good computing resources. A lot of collaborative research takes place on the whiteboard in the CECM lounge! The CECM lab is one of the best research spaces in the department. However, we have not been able to use the CECM lab since October 2019 when renovations began, and subsequently due to the pandemic. This has significantly impeded research collaboration between faculty and especially between students.

Since 1995, the CECM has collaborated with Maplesoft, the developer of Maple. This collaboration involves research and development of mathematical software for use by CECM members and the Maple community. Many of our students have contributed software to Maple through two NSERC CRD grants (2004-2009 and 2013-2017), two MITACS research grants (1998-2005 and 2005-2012), and several MITACS internships. This list of software contributions is long; it includes software for integer factorization, the GraphTheory package, a GroupTheory package, and the numerical recognition command Identify: for example input the decimal number 8.015236116 into Maple and Identify outputs the constant  $\sqrt{3} + 2\pi$ . Two recent contributions by Monagan and his students, namely polynomial factorization and Groebner basis computation, are summarized in the attachment Accomplishments.pdf.

### **The Centre/Institute's membership and organization structure:**

Director: Michael Monagan

Associate Director: Luis Goddyn

Computer Systems Administrator : John Hebron

Membership is available to SFU faculty and associate membership is available to non-faculty.

**Rationale for the renewal of the Centre/Institute:**

The mathematical software packages Magma, Maple, Macaulay2, Sage and Mathematica are used for research not only in mathematics but also in all branches of science and engineering. They are also increasingly being used in industry. For example, Maplesoft has a contract with Toyota to use Maple for car engine simulation. The CECM supports its members by providing a computational platform for these mathematical software packages and expertise in their application, support that a single researcher could not readily acquire.

Because these software packages have application in all areas of mathematics and science and engineering, it is highly desirable for SFU to have local expertise in these products and to have a medium size computing facility for users of these products.

Another advantage of a Centre is that we attract students to the discipline of mathematics. It has been very helpful to have student projects which use the computer to tackle real-world problems, to explore non-trivial examples of mathematical objects, to test conjectures and to write software routines and packages. In the last five years, 19 undergraduate students have done either an NSERC or VPR summer research project in the CECM lab using one of these mathematical packages.

Often the tools used in one discipline enable research in another. For example, tools such as Groebner bases that were developed for algebraic computation are now used for research in combinatorics, cryptography, algebraic geometry, and number theory. The CECM provides a venue where faculty and students can learn how to use these tools.

A Centre enables us to host larger research projects which require space for research personnel and computing infrastructure. For example, the CECM hosted Monagan and Lisonek's NSERC CRD project with Maplesoft from 2013 to 2017. The funding included \$240,000 from NSERC and \$120,000 from Maplesoft. Some of the funding was used to purchase a 20 core server in 2014 for parallel algorithm development. This machine, which we named jude, was used and is being used today by many members of the CECM. It is the most powerful machine that we currently have. The CECM lab housed two research personnel and several graduate students who worked on the project. The CECM server network hosted the research version of Maple which enables us to integrate our software into the Maple library and test it. Monagan is applying for a new NSERC Alliance grant with Maplesoft which we would like run through the Centre.

**How has the Centre/Institute enhanced research over and above what would have been accomplished by an individual faculty member?**

As just mentioned, the Centre enabled us to host Monagan and Lisonek's NSERC CRD project with Maplesoft.

We are more likely to obtain funds for the computing infrastructure (multi-core servers and desktops), software licenses and lab space for our students that will support our research if we work together rather than as individuals. Because the Centre provides a common support platform for a variety for faculty and their research programs, we have a better justification for arguing the impact and benefit for funding applications. And we are more

likely to get funds if the resources will be used by many faculty and students. We can also pool funds from our NSERC accounts for modest purchases. For example, four of us are sharing the cost of our Magma license.

The members of our Centre have collective expertise in many mathematical software packages. Often the tools used in one discipline enable research in another, as noted above. Sometimes this expertise is technical; How can I compute an asymptotic expansion of a particular function in Maple? Sometimes we need to write a program in one of the software packages and we just need help from a colleague. Sometimes watching a colleague show how to solve a problem using a mathematical software package will help us see how to solve a problem in our area of mathematics. The computer algebra systems Maple, Magma, SageMath, Macaulay2, Singular, and Mathematica that we use really are useful in many different areas.

Our Centre provides a physical space where students and faculty can interact with those in neighbouring disciplines. Faculty need a home to which they belong. Students also need a home and other students with whom to discuss their work. The pandemic has been particularly hard on students, both socially and professionally. It has made student interaction hard. While scheduled and impromptu Zoom meetings have helped with supervisory tasks, in-person interactions that naturally happen in shared lab space have been nigh impossible to replicate or replace online.

#### **How has the Centre/Institute accomplished its goals?**

CECM members have led and participated in the weekly/biweekly seminars in the Algebraic/Arithmetic Geometry and Number Theory Groups [Bruin, Ilten, Chen, Choi], the Computer Algebra Group [Monagan, Bruin, Lisonek, Ogilvie] and Discrete Mathematics Group [Goddyn, Jedwab, Lisonek, Mishna, Mohar].

John Hebron has maintained our computing servers maple (8 cores), gaby (16 cores), and jude (20 cores) and our file server and web server, and the desktop computers in the CECM lab and those in our faculty offices. The servers are being used for mathematical experiments and searches and parallel algorithm development. See the Accomplishments.pdf attachment which lists our most significant works using the CECM computers.

The CECM has provided some public instruction on the use of various mathematical software packages. For example, in May 2018, Daniel Skoog from Maplesoft gave the presentation on "What's new in Maple?" and Andrew Rourke from Maplesoft gave the presentation on Maple TA (Maple Teaching Assistant). We plan to do more such tutorials.

#### **Changes planned upon renewal (e.g. membership, organization structure, etc.):**

We are in the process of selecting a new Director.

We are moving some of the computing infrastructure (file sever, license and authentication server and web server) to the SFU cloud and two or the compute servers to the SFU Tower for increased reliability.

We will hold an annual lab meeting to discuss issues around EDI, in particular how to create an inclusive, respectful and welcoming environment for all.

We will hold regular software tutorials for the packages Maple, Magma, SageMath and Macaulay2, and make recordings available on our web server.

We will hold an annual orientation meeting for new members and students.

We will redesign the main web pages.

**Significant accomplishments:**

1) A list of significant research accomplishments by members of the CECM and their students is given in the attached document Accomplishments.pdf. Each contribution consists of one or more research papers focusing on a mathematical or computational problem. I chose to restrict contributions to those which used the CECM computing facility. The CECM computing facility is a Linux network of desktop workstations (mostly quad-core) and multi-core servers.

2) A list of HQP who worked in the CECM lab and/or used the CECM computers in the period 2016-2021 is given in the attached document HQP.pdf. The list gives each student's degree if completed and their research topic. The list includes 2 PDFs, 25 graduate students and 20 undergraduate students. The list of topics conveys an overall sense of the research topics of current interest to the CECM members.

**Notable media successes:**

NONE

**Events, workshops, public outreach events:**

1) The CECM initiated an annual one day workshop in 2003 with the title "Computational Mathematics Day" where students presented their work on posters and faculty and visitors gave invited talks. We held the event at the end of the summer semester so that our NSERC summer research students could participate. The workshop was extended into a Department-wide event in 2010. Every year the CECM gave cash prizes for the best graduate and undergraduate student poster.

In order to attract participation from other departments which have an interest in mathematics and computation, we rebranded the meeting as the SFU Symposium on Mathematics and Computation in 2015. Members of the CECM have continued to support the event by presenting their work, contributing financially to the awards, and helping with the organization. For example, at the 2018 event there were 5 talks and 21 posters . 5 of the posters were presented by CECM students (Chorney, Hearn, Zotine, Tuncer, Paluck) and 6 posters were presented by students from outside of the Department of Mathematics.

The event was held in 2015, 2016, 2017, 2018, 2019 but was cancelled for 2020 and 2021 due to the pandemic.

2) We have hosted Maplesoft personnel giving presentations on new Maple software packages and tools to the Department.

In May 2018 Daniel Skoog spoke on "What's new in Maple?" and Andrew Rourke, spoke on Maple TA. In July 2018 Erik Postma spoke on "What's new in Maple?"

**The Centre/Institute's multi-year goals for the next renewal term:**

1) Continue to provide member access to mathematical software packages Maple, Magma, SageMath, Macaulay2 and Matlab, and other packages as the need arises.

At this time we need to renew our Magma license. We are also discussing the purchase of a Mathematica license.

**KPI 1:**

NONE

2) To provide expertise and training in the use of mathematics software packages. We have been doing this occasionally. We now plan to give regular tutorials for Maple, Magma, SageMath and Macaulay2, at least one per year. These tutorials can be made accessible to other SFU faculty and students. We will record them and make the recordings available on the CECM web server.

**KPI 2:**

The number of tutorials given per year.

3) Continue to provide systems support for the servers, desktops, and web server and to provide a web presence for members for their papers, talk slides, videos, etc. John Hebron of the Network Support Group is currently providing system support.

To simplify the work John is (1) moving the file server and web server to the SFU cloud, (2) retiring the stan and maple compute servers, (3) moving the gaby and jude servers to the Tower which has a more reliable power supply, and (4) retiring the CECM email server.

**KPI 3:**

NONE

4) Provide multi-core servers for exploratory computations, searches, and (parallel) software development. You may be thinking, why don't they just use Compute Canada computers? Because Compute Canada provides a batch service. For software development we need to be able to compile, execute, debug, compile, execute, debug, dozens of times in a day. One cannot develop software in a batch computing model. Our Department budget includes a request to the Dean of Science for \$10,000 to purchase a new compute server with two 24 core Intel Gold 6342 CPUs which will cost circa \$16,000 + taxes. The new machine will be on the CECM network and so accessible to all members. Maplesoft has offered to contribute \$5,000. We have \$2,000 available for equipment purchase in an old account.

**KPI 4:**

Securing this money!

5) Provide a collaborative space for students, visitors and faculty to meet and work in by rebuilding the CECM lab community after the pandemic. We have a newly renovated lab with whiteboards and blackboards (yes, many of us prefer blackboards) ready for use as soon the pandemic is over. The Director will need to hold an EDI training meeting with the people in the lab.

**KPI 5:**

Attendance.

6) New member recruitment and member orientation. We plan to hold a CECM Day information event annually where we invite faculty and students to see the CECM lab and hear what facilities are provided by the centre. At this time we have reached out to two new faculty in the Department to see if they wish to become CECM members.

**KPI 6:**

Attendance.

7) To support collaborative research and development grants with industry by providing computing resources and lab space for graduate students and other project personnel. Maplesoft has agreed to collaborate with Monagan and apply for a small NSERC Alliance Grant.

**KPI 7:**

Number of HQP trained and software contributions to Maple.

8) Continue to support the annual SFU Symposium on Mathematics and Computation summer meeting at SFU by providing financial support and speakers, and encouraging students to attend and present their research work in poster form.

**KPI 8:**

Count the number of CECM supported students who attend and present posters each year.

9) Continue to provide venues for sharing new research results. Currently we do this informally in the CECM lab and by giving seminars in the four research groups to which members belong, namely

Computer Algebra Group:

<http://www.cecm.sfu.ca/CAG/>

Discrete Mathematics Group:

<http://www.sfu.ca/math/research/discrete-mathematics.html>

Number Theory Group:

<http://www.sfu.ca/math/research/number-theory.html>

Algebraic and Arithmetic Geometry Group:

<http://www.sfu.ca/math/research/algebraic-and-arithmetic-geometry1.html>

**KPI 9:**

The record of the talks given on group webpages.

**10)** Continue to provide HQP training in mathematics research and/or mathematical software development for undergraduate and graduate students. Experience in software development, and proficiency with a range of mathematical software packages, will be of great benefit in students' future careers, whether in industry or academia.

**KPI 10:**

Number of HQP trained.

**Supporting documents:**

- 1) Accomplishments\_Jfo77Ga.pdf (See attachment below)
- 2) HQP\_OrRsUMJ.pdf (See attachment below)
- 3) Membership\_MNyihq1.pdf (See attachment below)

## Financial Summary

**Does your Centre/Institute receive direct financial support from the university?**

Yes

**SFU account number:**

N875890

**Opening balance:**

\$6,138.09

**Revenues:**

\$0.00

**Expenditures:**

\$372.00

**Closing balance:**

\$5,766.09

**Financial report:**

N875890\_vfaylpc.pdf (See attachment below)

**Financial contributions from the university:**

NONE

**List of major equipment provided by the university:**

NONE

**University personnel:**

John Hebron, of the Network Support Group, spends about one day per week maintaining the computing infrastructure (severs, desktops, software licenses, operating systems).

**Space provided by the university:**

P8495. This is the CECM research lab space.

It was closed in October 2019 for renovations and has remained closed through the pandemic. The renovations have been completed. We are very grateful for this space. We have our graduate students occupying it and, in the summers, we squeeze in another 4 or 5 undergraduate students who are doing an NSERC USRA, and, in the fall, host undergraduate students doing MATH 499 Honours Research Project.

**Was the Centre/Institute leveraged to attract external funding (donations, grants, contracts) which were only made possible by its existence?**

Yes

**External funding details:**

NSERC CRD with Maplesoft, 2013-2017. Maplesoft put up \$150,000 in total of which the Dean of Science received \$15,000 which was forwarded to the CECM as the project was run on the CECM computers (the CECM hosted research and development version of Maple). This is the source of the funds in account N875890. We also have another account S210240 with \$4350 in it. The source of this money is two donations of \$5000 from Maplesoft.

**Confirm policy review:**

Yes

**Submitted by:**

Michael Monagan, Director

**Director's comments:**

I have directed the CECM for 10 years. It is time to pass the baton to a new director who will bring new energy and new ideas to ensure the continued success of the CECM. Nils Bruin has accepted a nomination to be the new director. We will hold a ratification vote in July after Nils has had time to speak with the members.

We have a newly renovated lab space in P8495 which will be a wonderful asset as it will surely again be the place where faculty, students and visitors meet to work together. Thanks are due to the Dean of Science for funding the renovations and Dale Yamura of Mathematics for making this happen.

We have applied to the Dean of Science through the department for \$10,000 to go towards the purchase of a new multi-core computer with two 24 core Intel Gold 6342 CPUs which will provide many years of computing resources for the members at a modest price. We need this computer. The two best computers that we have, gaby and jude, were purchased in 2012 and 2014. We have failed twice to obtain an NSERC RTI grant for this purchase.

We are creating a new schedule for regular tutorials on the mathematical software packages that we mainly use, namely, Maple, SageMath, Magma, Macaulay2 and possibly also C and Mathematica. As we learn how to use these packages, this is very likely to initiate collaborations, especially between those presenting the tutorials and those attending them. Maple and Mathematica tutorials will be of interest to members of other departments at SFU.

The university has requested that we add the word "Research" to the title of the Centre.

The Centre is universally referred to by its acronym CECM, and has significant brand recognition worldwide, without explicit reference to what the letters in the acronym stand for. The CECM was founded in November 1993 by the Borwein brothers Jon and Peter and the 28 year legacy of name recognition is considerable and global. It is therefore in the best interest of the Centre (and, by extension, also in the best interest of SFU as the hosting institution) to maintain the integrity of the acronym. We can refer to the Centre as "The CECM Research Centre" where explicit mention of the "Research Centre" nature is important.

We propose that we do that going forward and that legacy, archived content and publications are maintained as-is, for historical accuracy and also for practical reasons, since we do not have the resources to rewrite history concerning the name of the Centre.

I am pleased to report that Dr. Jake Levinson who started at SFU in Fall 2020 has accepted my invitation to become a member of the CECM. Jake works in algebraic geometry and algebraic combinatorics.

Michael Monagan

## **Reviewer's Section**

**Reviewed by:**

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**Reviewer's decision:**

None

**Reviewer's comments:**

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