Computing in Science Education (CSE)

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CSE is about deep integration of computing in the curriculum

Strong focus on IT in eduction but...

- mostly for communication
- minor impact on the *contents* of courses and textbooks

CSE: Why not...

- use numerics, programming and simulation from day 1?
- create the future science courses?

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The science curriculum does not reflect reality

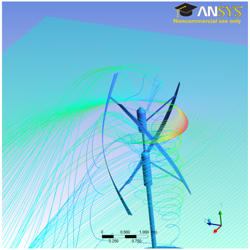
Teaching:

Simplified problems with pen and paper.

Research/industry:

Complex problems solved by computing.

The computing reform is more central than ever



Two paradigms: use software - or do programming?

CSE: strong emphasis on programming.

1. Great demand for candidates who master problem solving via programming
2. We believe "programming is understanding"

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"Programming is understanding" (K. Nygaard)

Make a new data type for polynomials:

```
p1 = Polynomial({0: 1, 1: -1})          # 1 - x
p2 = Polynomial({1: 1, 4: -6, 5: -1})   # x - 6x^4 - x^5
p3 = p1 + p2                            # shown in detail
p4 = p1*p2                              # exercise
print p4       # x - x^2 - 6x^4 + 5x^5 + x^6
```

Everybody is drilled in polynomial multiplication,

$$(1 - x)(1 - 6x^4 - x^5) = \ldots$$

but programming involves *general polynomials* (not specific ones!):

$$\left(\sum_{i=0}^{M} c_i x^i\right)\left(\sum_{j=0}^{N} d_j x^j\right) = \sum_{i=0}^{M}\sum_{j=0}^{N} c_i d_j x^{i+j}$$

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What we have learned about programming

- Lectures and exams must involve programming
- Programming must be a primary activity
- Recall: *we learn what we do every day*

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Integration of mathematics, numerics, programming and simulation at the University of Oslo

1st semester.

Classical calculus I, Numerical calculus, Scientific programming

2nd semester.

Classical calculus II w/numerics, Physics w/numerics

3rd semester and beyond.

Classical calculus III w/numerics, lots of science courses use programming and simulation

Challenge: make impact on chemestry, geology and biology

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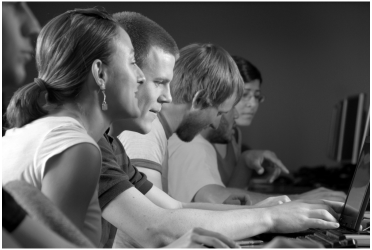
Highlights of great results from the CSE project

From student projects:

- Journal publication (Vistnes)
- Found error in recent paper (Malthe-Sørenssen)



Students are a great resource and have contributed much to the development CSE!

Many rewards of a successful CSE implementation

The student:

- Better motivation and understanding
- More realistic problems and workflow
- More operational: computationally proficient professionals

The researcher:

- Inspiring, renewed teaching environment - based on research
- More operational master and phd students

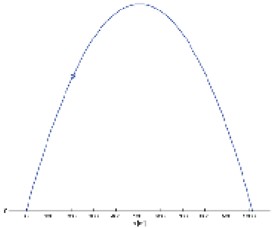
The institution:

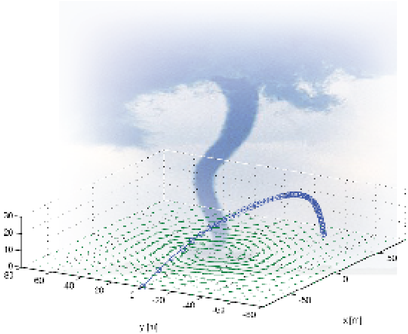
- Development of textbooks and material gives visibility
- Increased focus on teaching
- Teaching collaborations foster research initiatives

Computing provides generally applicable solution techniques

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

With computing we can do more realistic problems





Computing emphasizes forward vs inverse modeling

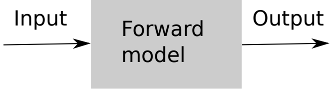
What is the interest rate if an investment doubles in five years?

$$\text{School:} \quad A = A_0 \left(1 + \frac{p}{100}\right)^n$$

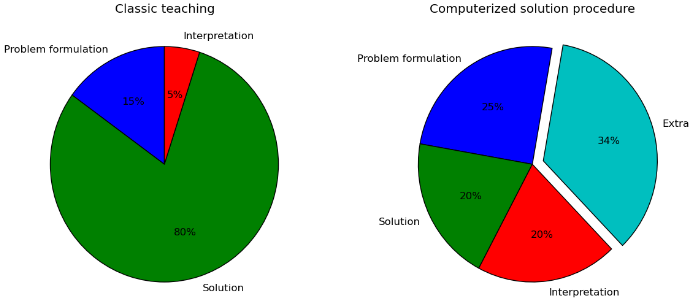
Fundamental model:

$$A_{n+1} = A_n + A_n \frac{p_n}{100}, \quad A_0 \text{ given}$$

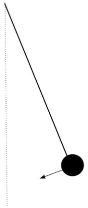
- Input: p, A_0
- Output: $A_1, \ldots, A_N$



Computing frees time for more focus on problem formulation and results



With computing complex is often simpler



$$\ddot{\theta}(t) + \omega^2 \sin(\theta(t)) = 0$$

Original/fundamental model (DAE):

$$m\,\ddot{\mathbf{r}} = \mathbf{F}$$
$$||\mathbf{r}|| = \text{const}$$

Parts of **F** unknown, parts of **r** known.
Elastic rope gives a clean Newton's 2nd law:

$$m\ddot{\mathbf{r}} = \mathbf{F}(\mathbf{r}, \dot{\mathbf{r}})$$

How to get it all to work

- Need a collaborating and acknowledging culture among the professors
- Need enthusiasm at the top (deans) and bottom (teachers)
- Need support from strategy plans
- 50K award for reforming a course

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Key people involved in running the CSE project

- Knut Mørken, Dept. of Mathematics
- Hanne Sølna, Faculty administration
- Annik Myhre, former Dean of Education
- Solveig Kristensen, Dean of Education
- Morten Hjorth-Jensen, Dept. of Physics
- Anders Malthe-Sørenssen, Dept. of Physics
- Øyvind Ryan, Dept. of Mathematics
- Hans Petter Langtangen, Dept. of Informatics and Simula lab.
- $+$ lots of professors and students