Formal software engineering for computational modelling

Formal software engineering

- Focus on the formal, mathematical side of software

- Ex. Algebra

- Three problems
  - What are the concepts that have to be used for the construction of software in this domain
  - What is a good programming notation for these concepts
  - How can they be implemented as software code

- Domain specific language (DSL)

- Domain specific embedded language (DSEL)

Software process model for developing DSEL

- Establish an appropriate DSL
- Validate the suggested DSL
  - Usefulness
  - Implementability
- Decide the architecture of the software library
- Design and implement a prototype
- Maintain the library

Establish an appropriate DSL

- Algebraic specification

- Ring

$$
\begin{aligned}
+ &: R, R \to R, \\
- &: R, R \to R, \\
* &: R, R \to R, \\
0 &: \to R, \\
1 &: \to R.
\end{aligned}
$$

$$
\begin{aligned}
(a + b) + c &= a + (b + c), &\quad (1) \\
a + b &= b + a, &\quad (2) \\
(a * b) * c &= a * (b * c), &\quad (3) \\
(a + b) - b &= a, &\quad (4) \\
0 + a &= a, &\quad (5) \\
1 * a &= a, &\quad (6) \\
a * 1 &= a, &\quad (7) \\
(a + b) * c &= (a * c) + (b * c), &\quad (8) \\
a * (b + c) &= (a * b) + (a * c). &\quad (9)
\end{aligned}
$$

Validate the suggested DSL

- Usefulness
  - Searching for oil
- Implementability
  - Discretization

$$
\begin{aligned}
\rho \frac{\partial^2 \vec{u}}{\partial t^2} &= \nabla \cdot \sigma + \vec{f}(t), \\
\sigma &= \Lambda(e), \\
e &= \mathcal{L}_{\vec{u}}(g).
\end{aligned}
$$

Elastic wave equation

Software architecture

- How to arrange different concepts
- Mesh (S or P)
- Scalar fields (Discretization)
- Tensors (coordinate system)

Results

Configuration	seismic	ultrasonic in borehole
Mesh	D S or P	D S or P
Tn	D S	D S
Bn	D S or U	D U
Tensor	SI or TI or TA	UI or UTI
Seismod	SE or PE	SE or PE

Module	D	S/SI/SE	P	TI	TA	U/UI	UTI	PE
Mesh	2000	2000	2700					
Tn	1700	1600						
Bn	1500	1900				2100		
Tensor		1000		1000	1800	1000	1100	1200
Seismod		600						700

Total: 12300 5500 4200 1900