FieldML: Data Structures for Modelling

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Objective

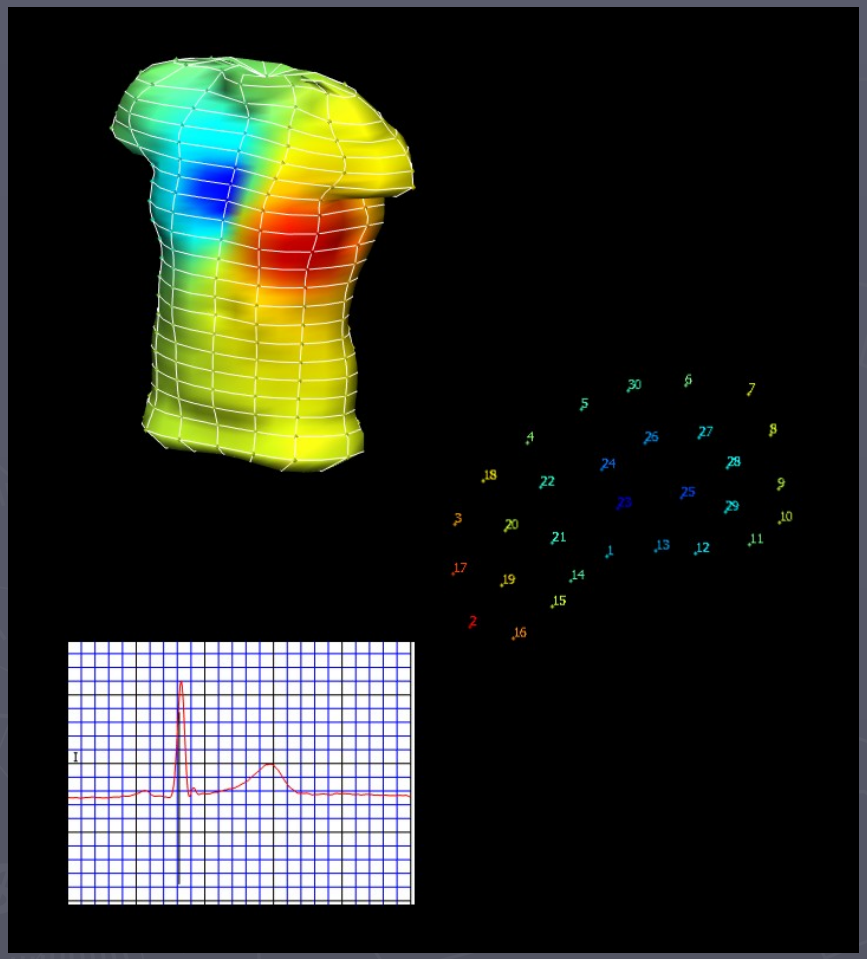
- Expressive, efficient representation of fields based on minimal set of concepts.
- From this, create serialization format (ML) to interchange modelling data.

... Most packages will only be able to read or write a fraction of the format, translating to their internal structures.

What is a Field?

- “A set of values defined over some domain”
- Domains:
  - Discrete (list of items, e.g. points)
  - Continuous (coordinate system, element/chart)
  - Combinations (mesh/atlas, time signals)
- Values:
  - Real, integer, string, object…
  - Multiple components or sub-fields (vectors, tensors)

Example Fields

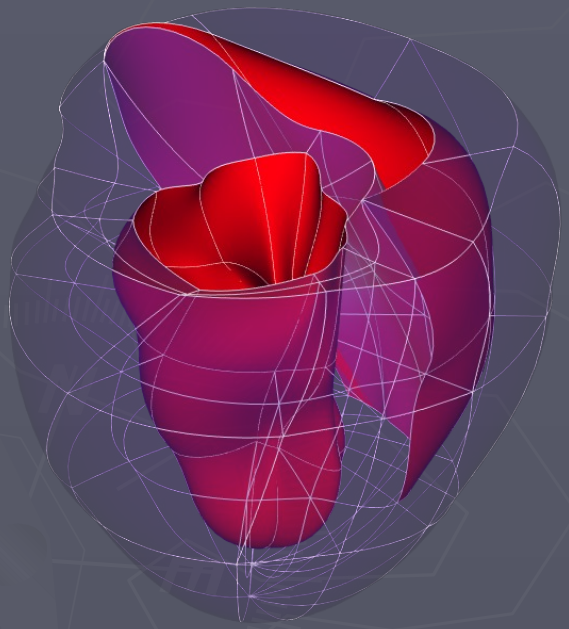


- Spatially-varying coordinates, scalar.
- Data points. (Analogy with fields in database records.)
- Signals, interpolation in time.

What's so special?

- "Everything is a field"; a necessary abstraction to deal with size and complexity:
  - Each field representation only as detailed as problem requires.
  - Arbitrary variation of any field with any other field.
- From minimal set of concepts, serialized format will be largely self-describing: e.g. basis functions defined with MathML expressions.
- C.f. typical FEM formats: fixed element types identified by magic numbers, special handling of coordinates, material properties etc. all leading to software limitations.

Building Block 1: Domains



- “Regions” introduce new namespaces for fields and sub-domains. Hierarchical; may encapsulate e.g. whole body or organ.
- Coordinate systems, lists (e.g. nodes), meshes (of particular interest).

… Are these just special types of field?

Building Block 2: Field Functions

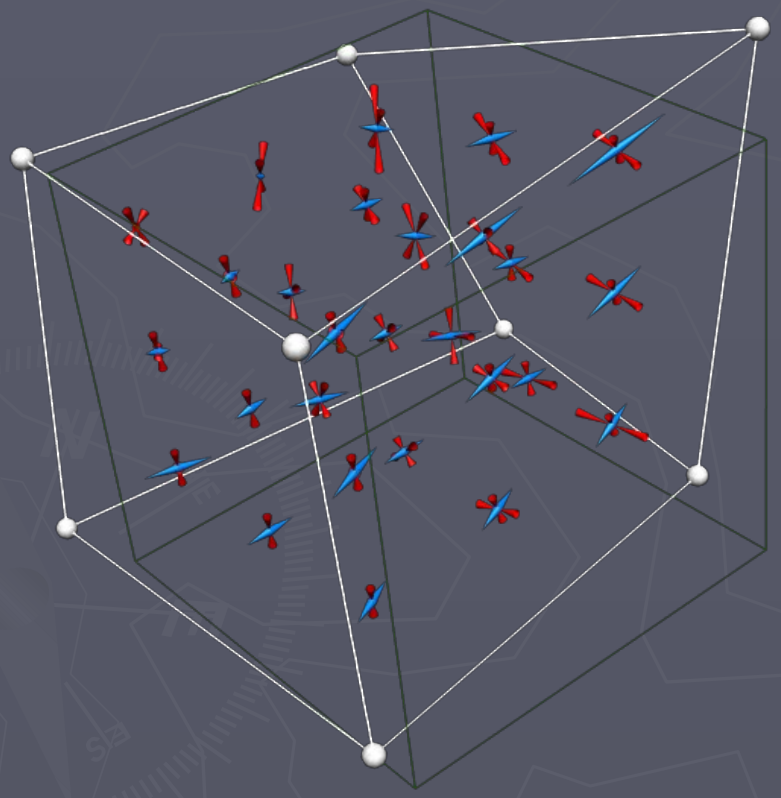
- Field values = f(source field values)
- Functions include field value lookup, mathematical functions, even values returned by software constructs not part of FieldML (e.g. texture lookup).
- Particularly interested in finite element fields = dot product of basis functions with element field parameters.

Building Block 3: Field Parameters

- Degrees of Freedom contributing to field (not necessarily values of field).
- Parameter lists stored in objects, e.g. field itself, or domain objects (nodes, elements).

... Are these just a special type of field? Mappings of parameters to elements are then same as field functions.

Field Compositions in CMGUI



```
gfx define field Identity3 composite 1 0
    0 0 1 0 0 0 1;
gfx define field F gradient coordinate
    undeformed_coordinates field
    deformed_coordinates;
gfx define field F_transpose transpose
    source_number_of_rows 3 field F;
gfx define field C matrix_multiply
    number_of_rows 3 fields
    F_transpose F;
gfx define field E2 add fields C Identity3
    scale_factors 1 -1;
gfx define field E scale field E2
    scale_factors 0.5 0.5 0.5 0.5 0.5 0.5
    0.5 0.5 0.5;
gfx define field principal_strains
    eigenvalues field E;
gfx define field principal_strain_vectors
    eigenvectors eigenvalues
    principal_strains;
```

Defining a finite element field

1. Define prototype element shape/chart field = xi
2. Define basis function field in terms of xi, e.g. MathML expressions
3. Define mesh field = set of elements with shape
4. Define discrete domain of nodes with nodal field parameters; alternatively global DOF vector.
5. Over each element:
    1. Define field function mapping nodal/global field parameters to element.
    2. Define continuous F.E. field as dot product of basis function and element parameters.

FieldML Challenges

- Handling Big Data. Need binary, compressed representations.
- Distributed memory multi-processing. Parallel I/O. Whole mesh connectivity needed to decompose mesh.
- Hierarchical meshes for Adaptive Mesh Refinement. Per-field refinement to minimise problem size.
- General embedded meshes.

FieldML Status

- All CMISS applications built with some level of FieldML concepts.
- We intend to develop open source CMGUI to follow full FieldML specification, but note migration issues and costs, plus some existing limitations:
  1. Incomplete implementation of Regions.
  2. Fixed nodal/element field parameter representations.
  3. Element parameter maps and basis functions are special/fixed functionality.
  4. Field composition functions are special; would like to add general mathematical formulas, e.g. MathML expressions.

Thank You!