Reusability of FEM Software: A Program Family Approach

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Outline

- Finite Element Method (FEM)
- Program Family
- A FEM Program Family: FEMBA

  - Goal-Oriented Commonality Analysis (CA)

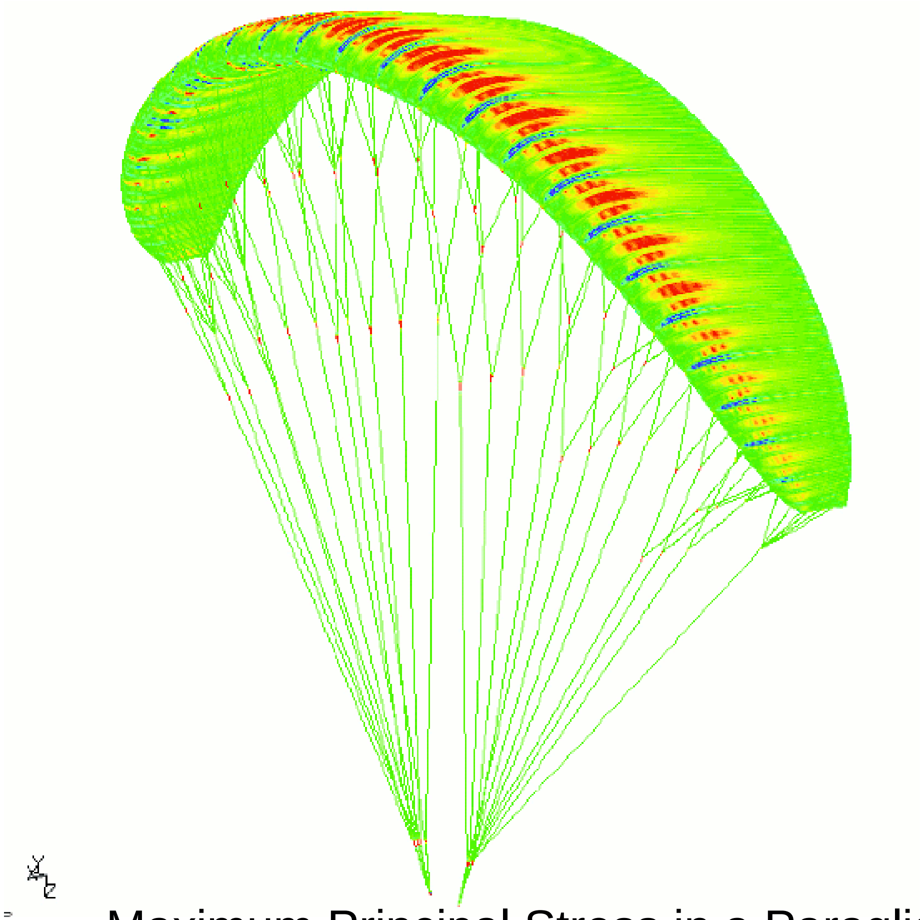
  - Documentation

  - Code Generation

Finite Element Method

- A numerical technique for solving PDEs

- A website maintained by Roger Young and Ian MacPhedran lists more than 100 public domain FEM programs



Maximum Principal Stress in a Paraglider
Solved by **CalculiX**

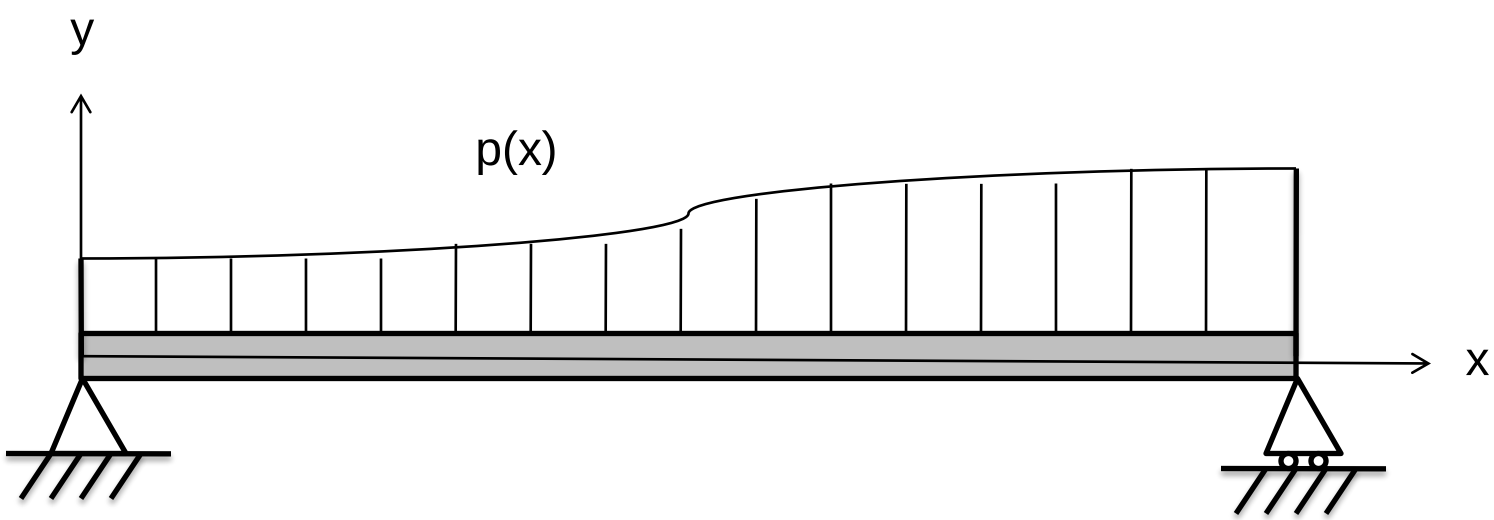
Program Family

- A set of programs that share a common set of features
- A commonality: the protocol
- A variability: the number of features

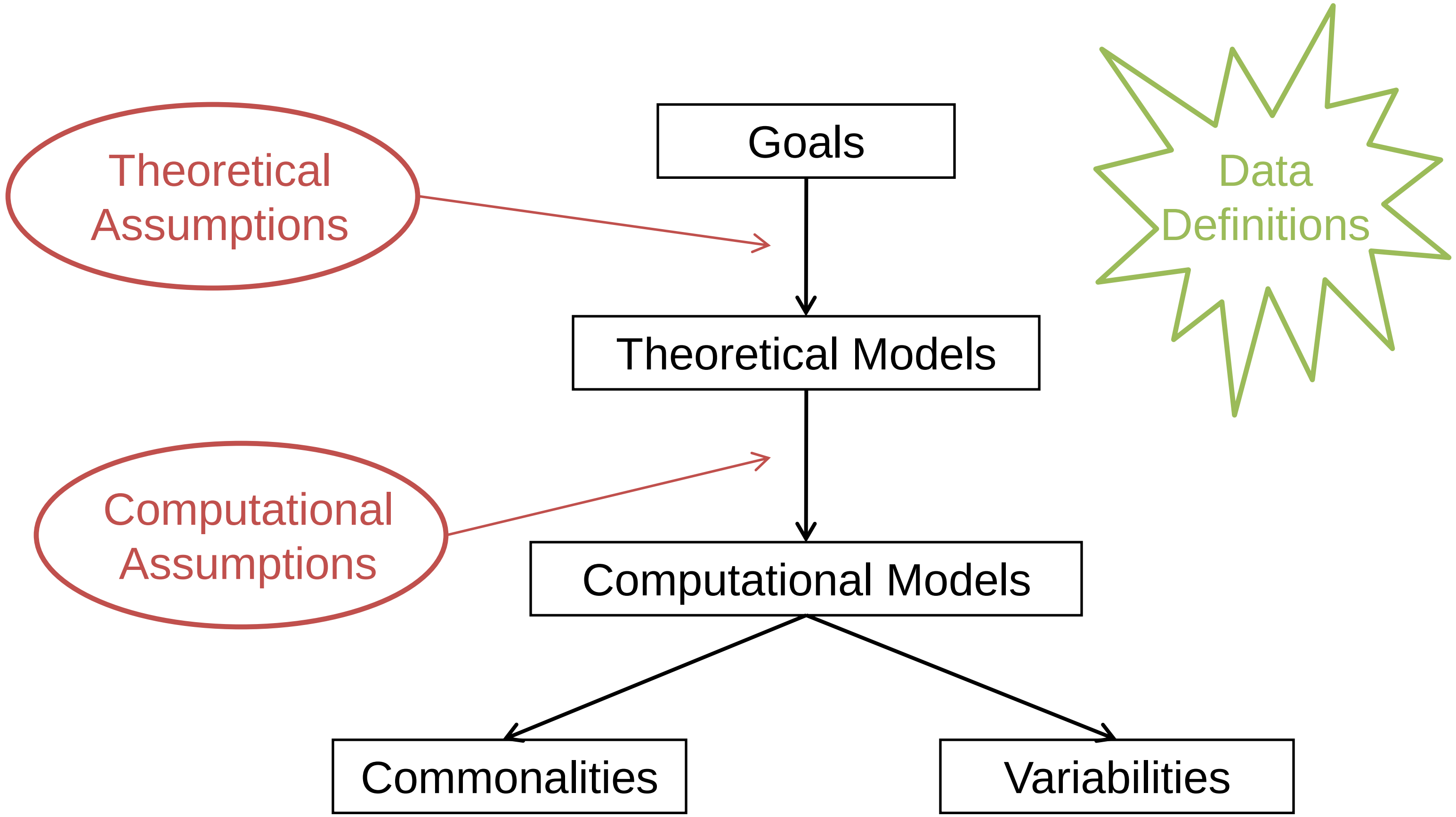
Pictures from CrunchGear

A FEM Program Family: FEMBA

FEMBA simulates a beam under an applied load using FEM



Goal-Oriented CA



Examples of CA for FEMBA (1)

- **G1** (gDis): FEMBA can solve for the displacement of a beam;
- **TA7**: The weight of the beam is neglected;
- **TM1** (tmDis): The equation to be solved for displacement is $d^4w/dx^4 = p(x)/EI$;
- **CA1** (caFEM): The problems are solved using FEM;
- **CM1** (cmDis): The formula for solving the displacement of each node is **Ka** = **F**;

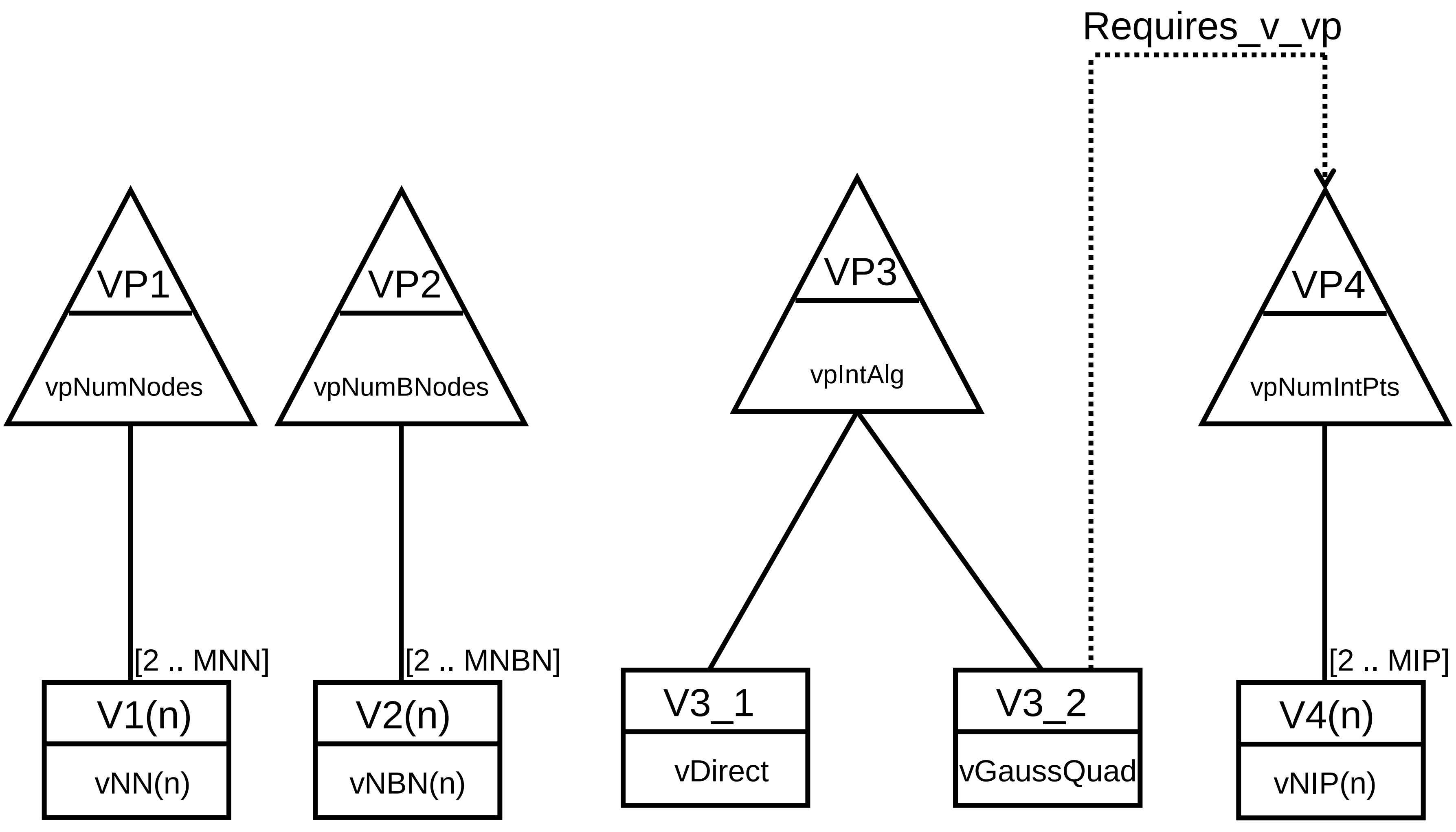
Examples of CA for FEMBA (2)

- **C4** (cDOF): Each node has two degrees of freedom (DOF)
- **VP1**(vpNumNodes): Each element has different number of nodes
- **D5** (dStiff): $\mathbf{K} = \int \mathbf{B}^T EI \mathbf{B} \, dx$

Documentation

- A program usually needs to be changed to be reused
- Documentation of variabilities and traceability matrices can help with the changes

Documentation: Variabilities



Documentation: Traceability Matrix

Traceability Matrix between Requirements and Modules (partial)

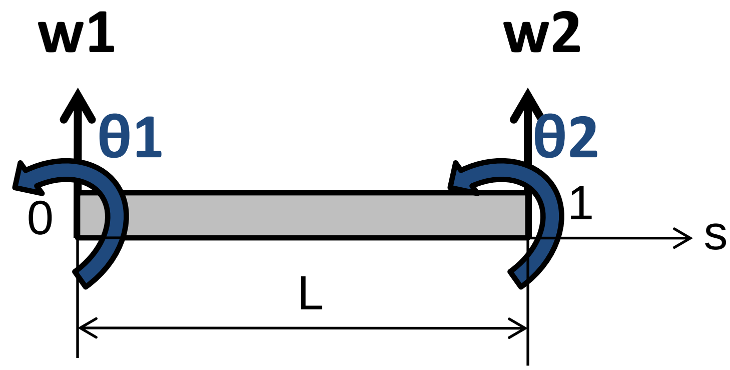
	mInMesh	mOutput	mControl	mStiff	mLoad	…
…						
cShear		√	√			
vpNum Node	√			√	√	
…						

Code Generation: Calculating K (1)

1. Find the shape functions $\phi_i(s)=c_{i1}+c_{i2}s+c_{i3}s^2+c_{i4}s^3$ for

$w=w_1\phi_1+L\theta_1\phi_2+w_2\phi_3+L\theta_2\phi_4$

$\theta=w'$



$\varphi_1(0)=1$	$\varphi_1'(0)=0$	$\varphi_1(1)=0$	$\varphi_1'(1)=0$
$\varphi_2(0)=0$	$\varphi_2'(0)=1$	$\varphi_2(1)=0$	$\varphi_2'(1)=0$
$\varphi_3(0)=0$	$\varphi_3'(0)=0$	$\varphi_3(1)=1$	$\varphi_3'(1)=0$
$\varphi_4(0)=0$	$\varphi_4'(0)=0$	$\varphi_4(1)=0$	$\varphi_4'(1)=1$

Code Generation: Calculating K (2)

2. Compute kinematics matrix **B**=A**N**, where
   A is the operator $(d^2/ds^2)/L^2$ and
   N=$[\phi_1\ L\phi_2\ \phi_3\ L\phi_4]$
3. Compute stiffness matrix **K**=$\int(\mathbf{B}^T EI \mathbf{B})dx$

Code Generation for FEMBA

- Calculating K is time consuming
- Use Maple to generate code for variabilities
- Use information hiding to develop FEMBA

Conclusion

- Program family approach can improve reusability by reusing commonalities
- Goal-oriented CA, documentation and code generation can improve reusability by helping with changes

Thank You !