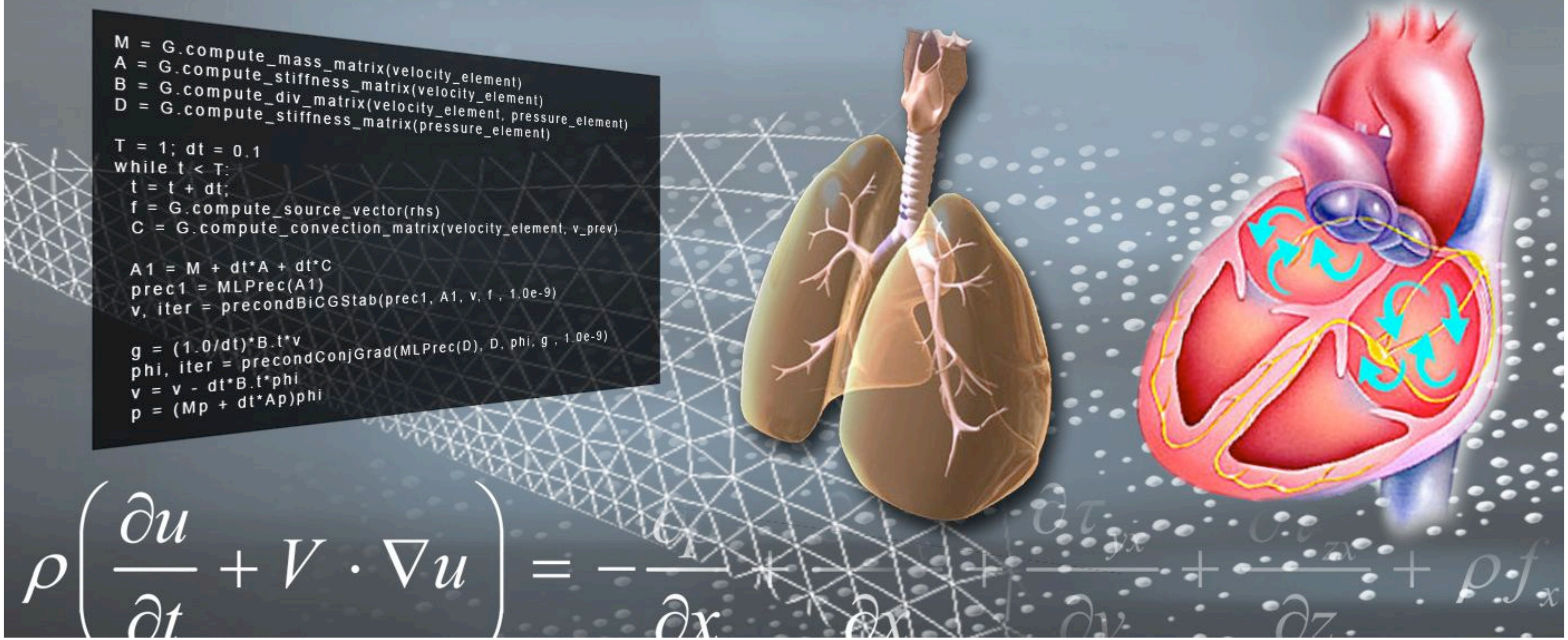
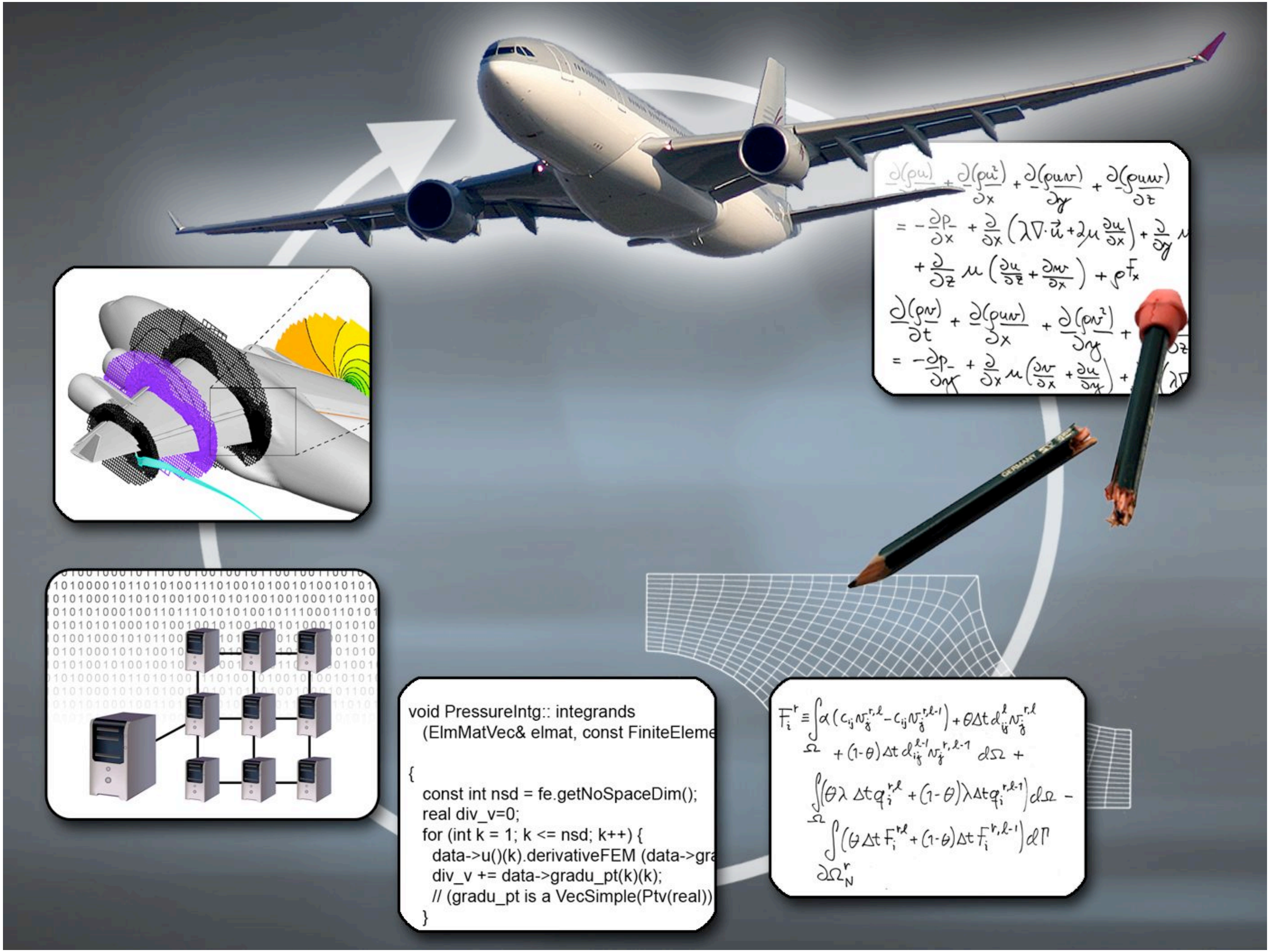
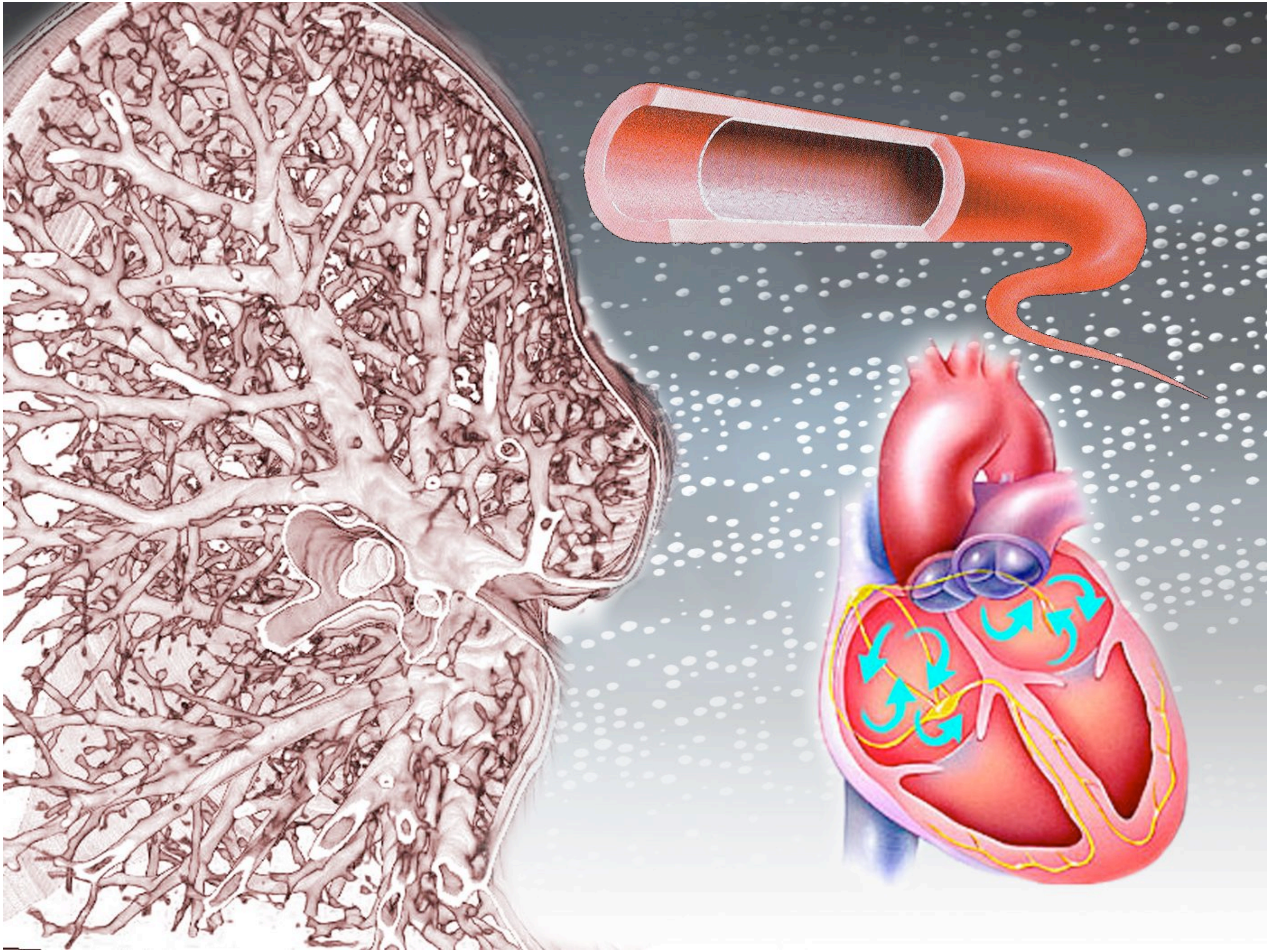
Center of Excellence

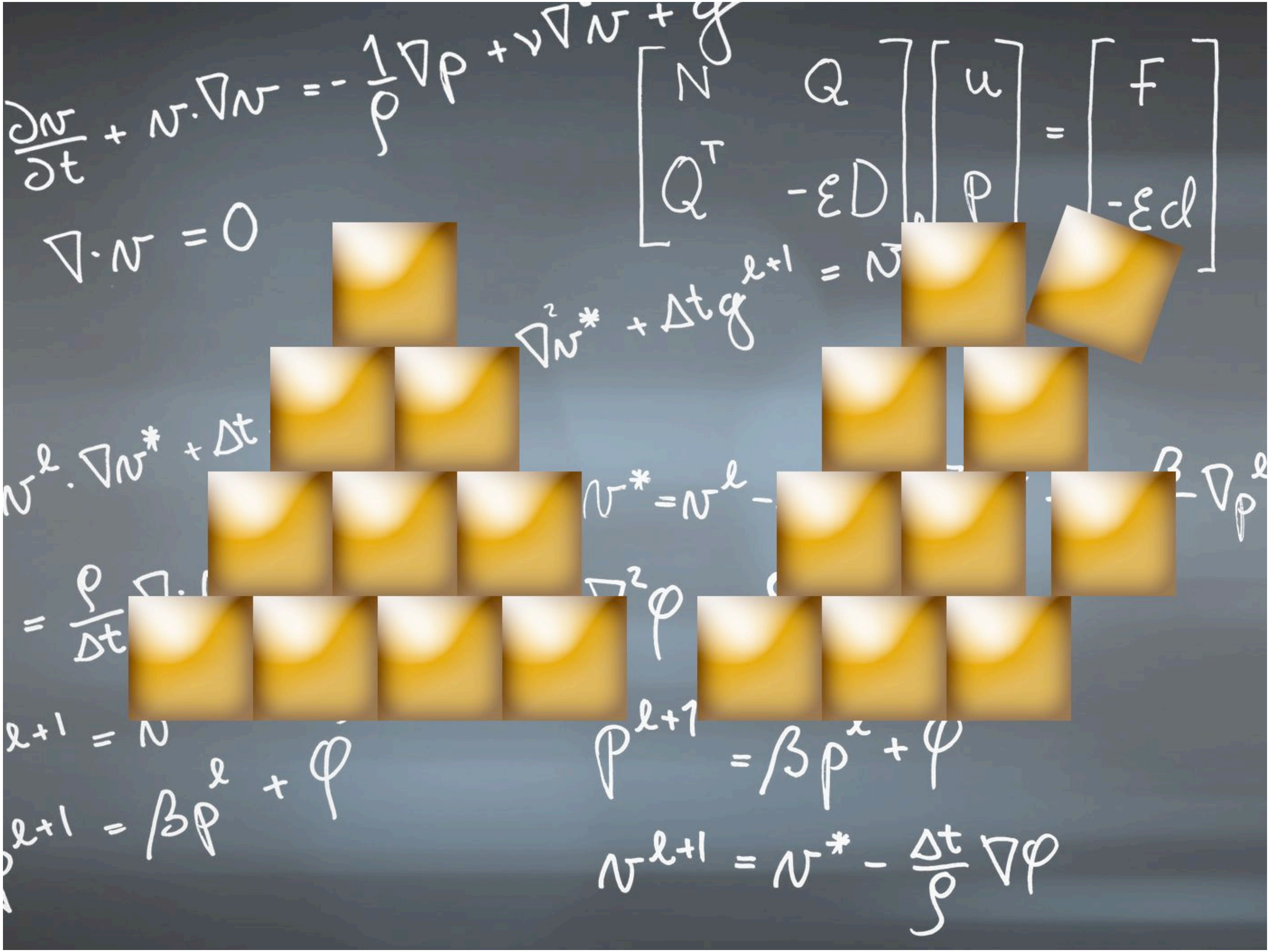
Software Components for Biomedical Flows

2007 - 2017

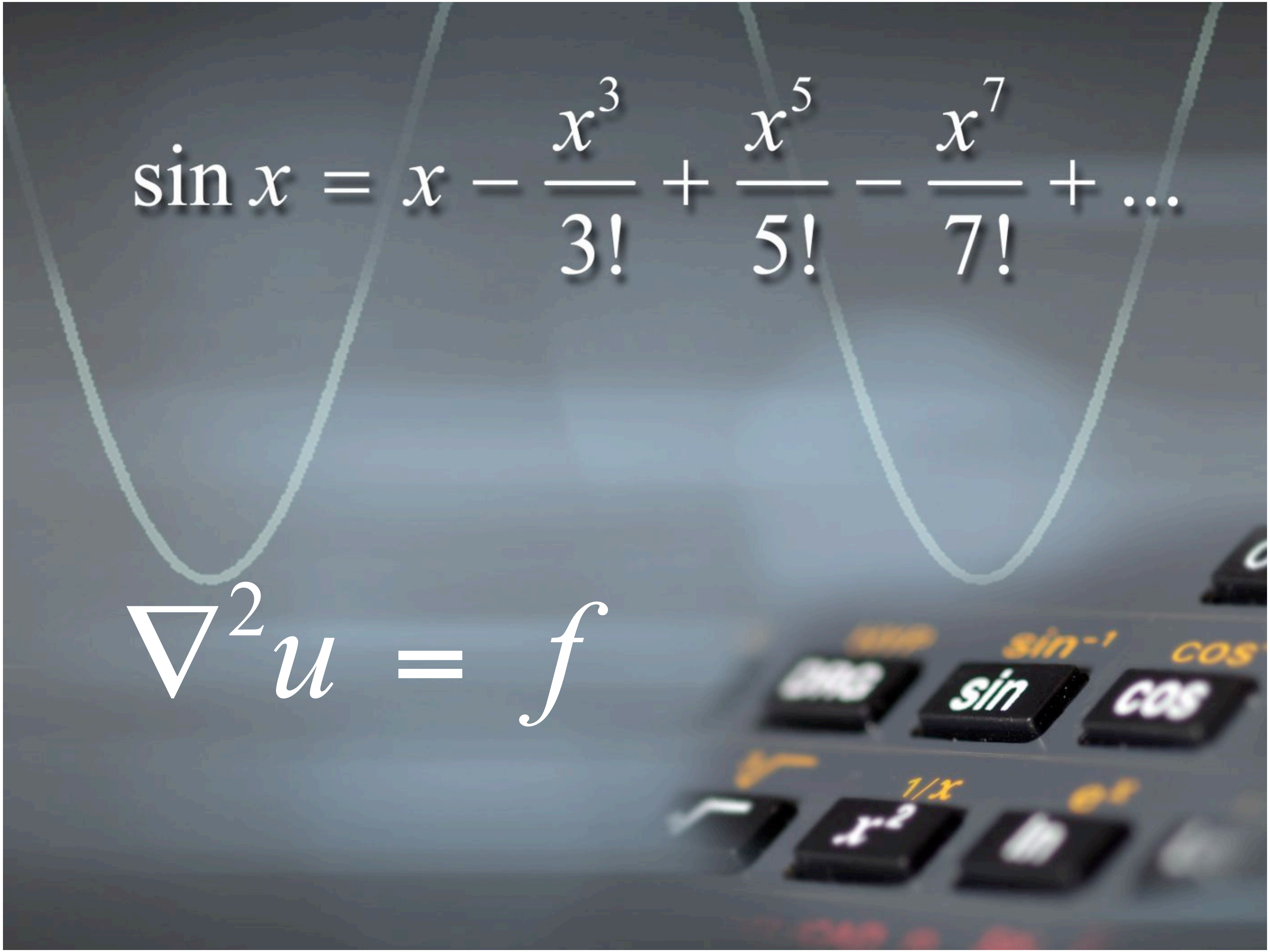


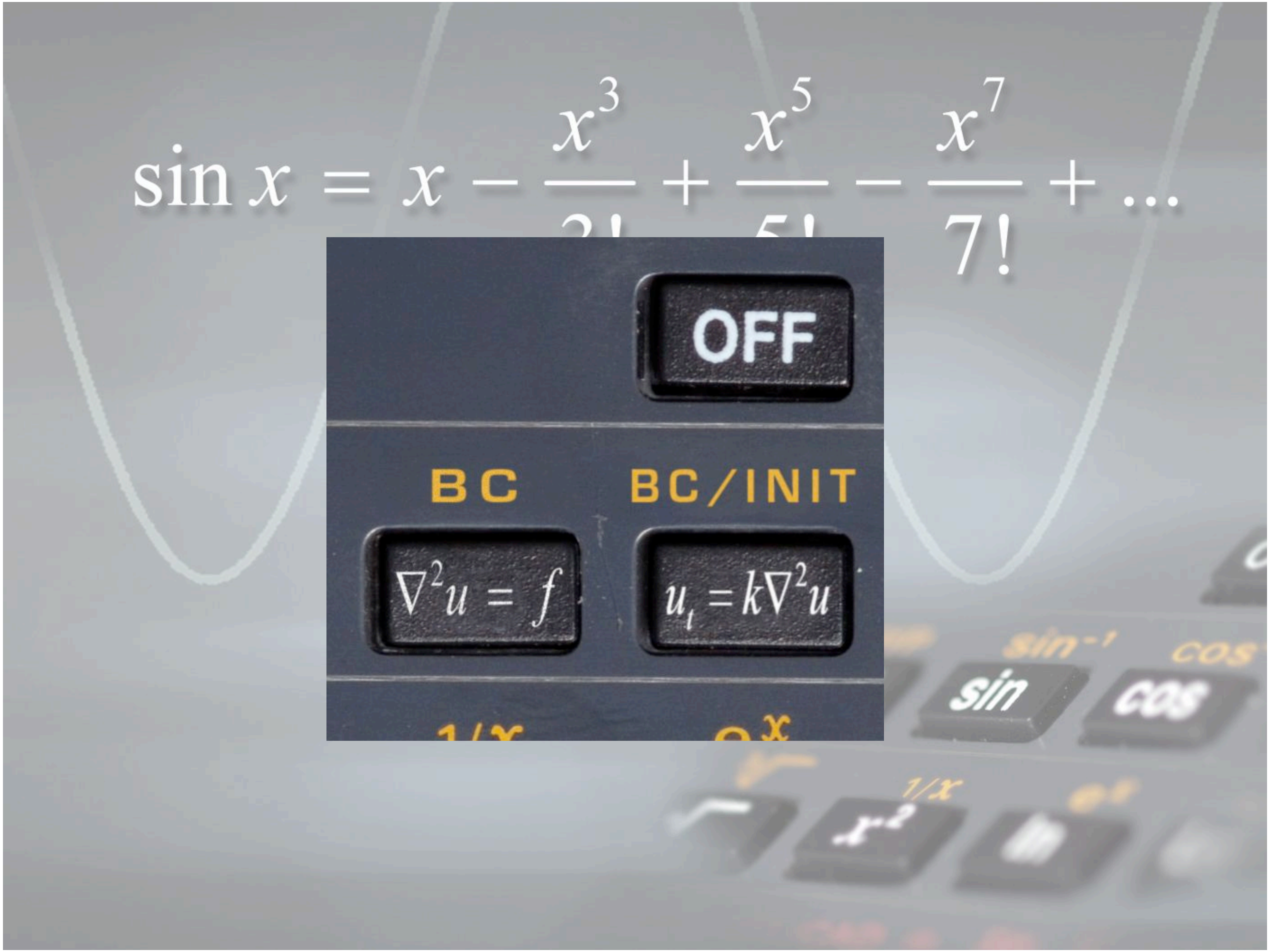

void PressureIntg:: integrands
(ElmMatVec& elmat, const FiniteEleme
{
const int nsd = fe.getNoSpaceDim();
real div_v=0;
for (int k = 1; k <= nsd; k++) {
data->u()(k).derivativeFEM (data->gra
div_v += data->gradu_pt(k)(k);
// (gradu_pt is a VecSimple(Ptv(real))
}



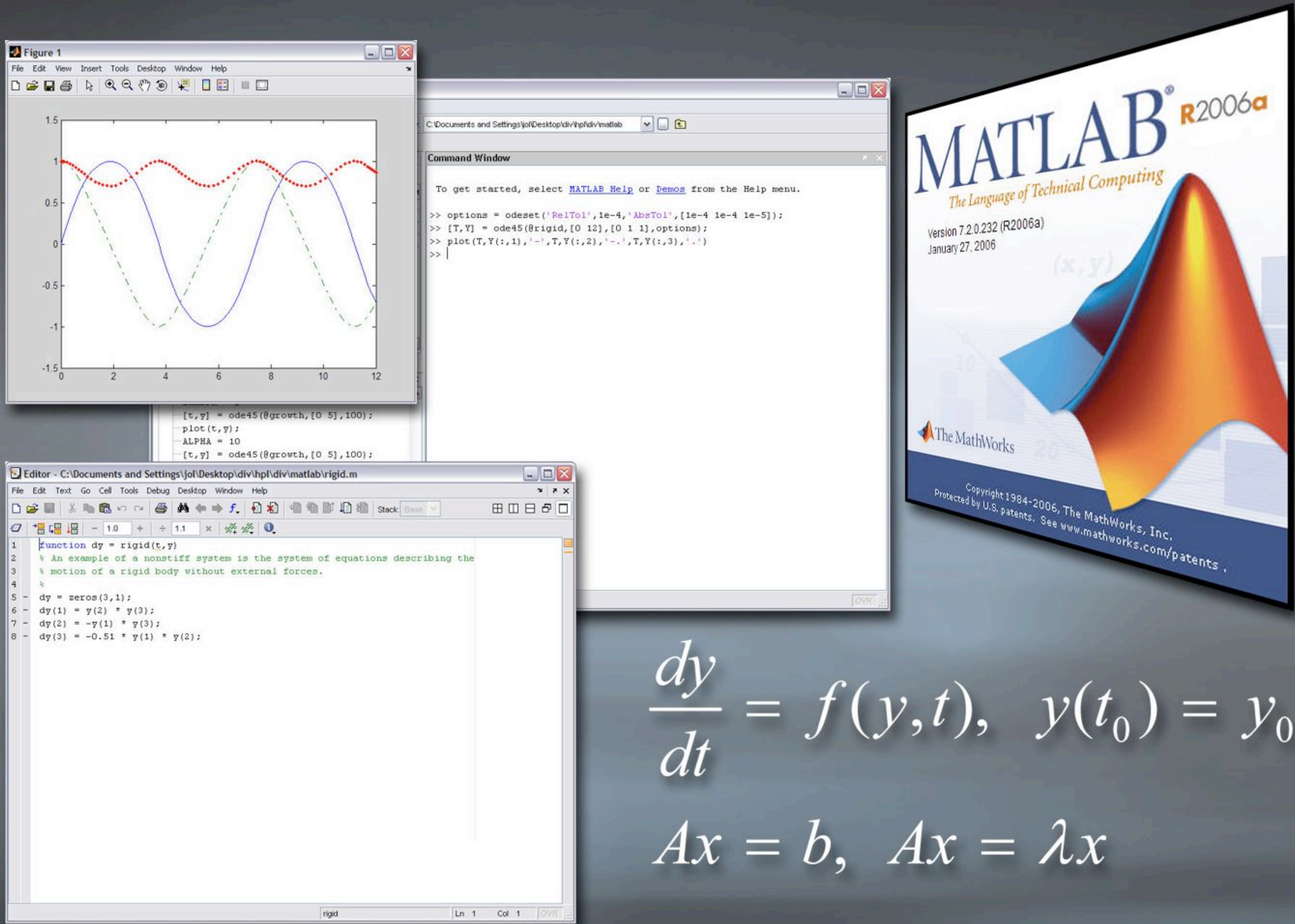


∇·v = 0
p^{l+1} = βp^l + φ
v^{l+1} = v* − Δt/ρ ∇φ


$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots$$
$$\nabla^2 u = f$$
$\sin^{-1}$
sin
cos
1/x
x^2



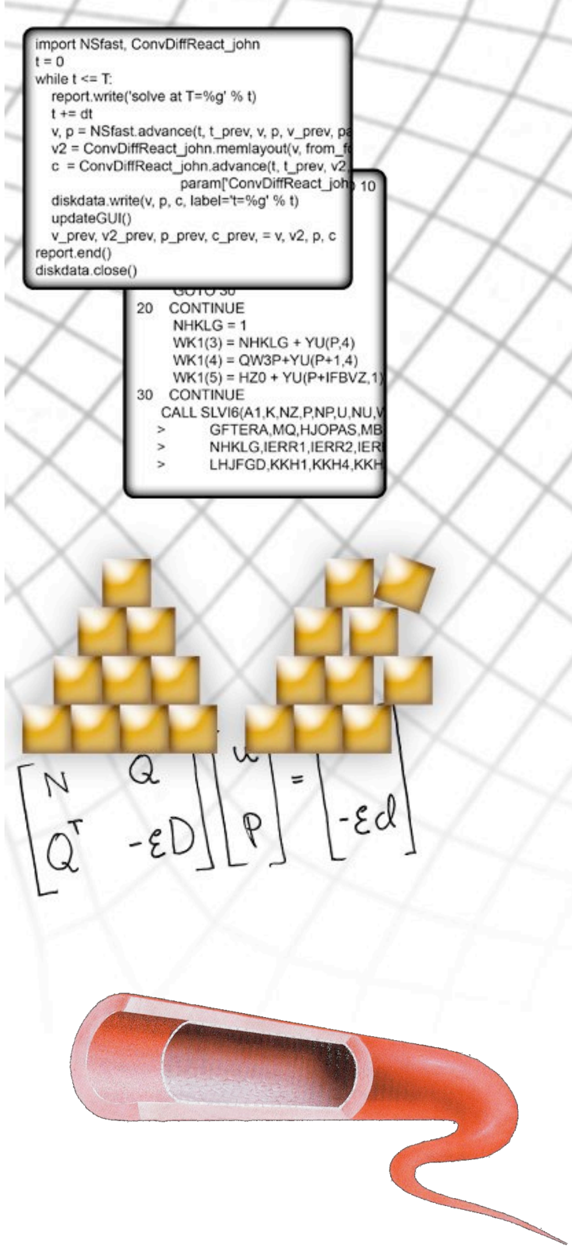
$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \ldots$
OFF
BC
BC/INIT
$\nabla^2 u = f$
$u_t = k\nabla^2 u$
sin
cos



$$\frac{dy}{dt} = f(y,t), \quad y(t_0) = y_0$$

$$Ax = b, \quad Ax = \lambda x$$

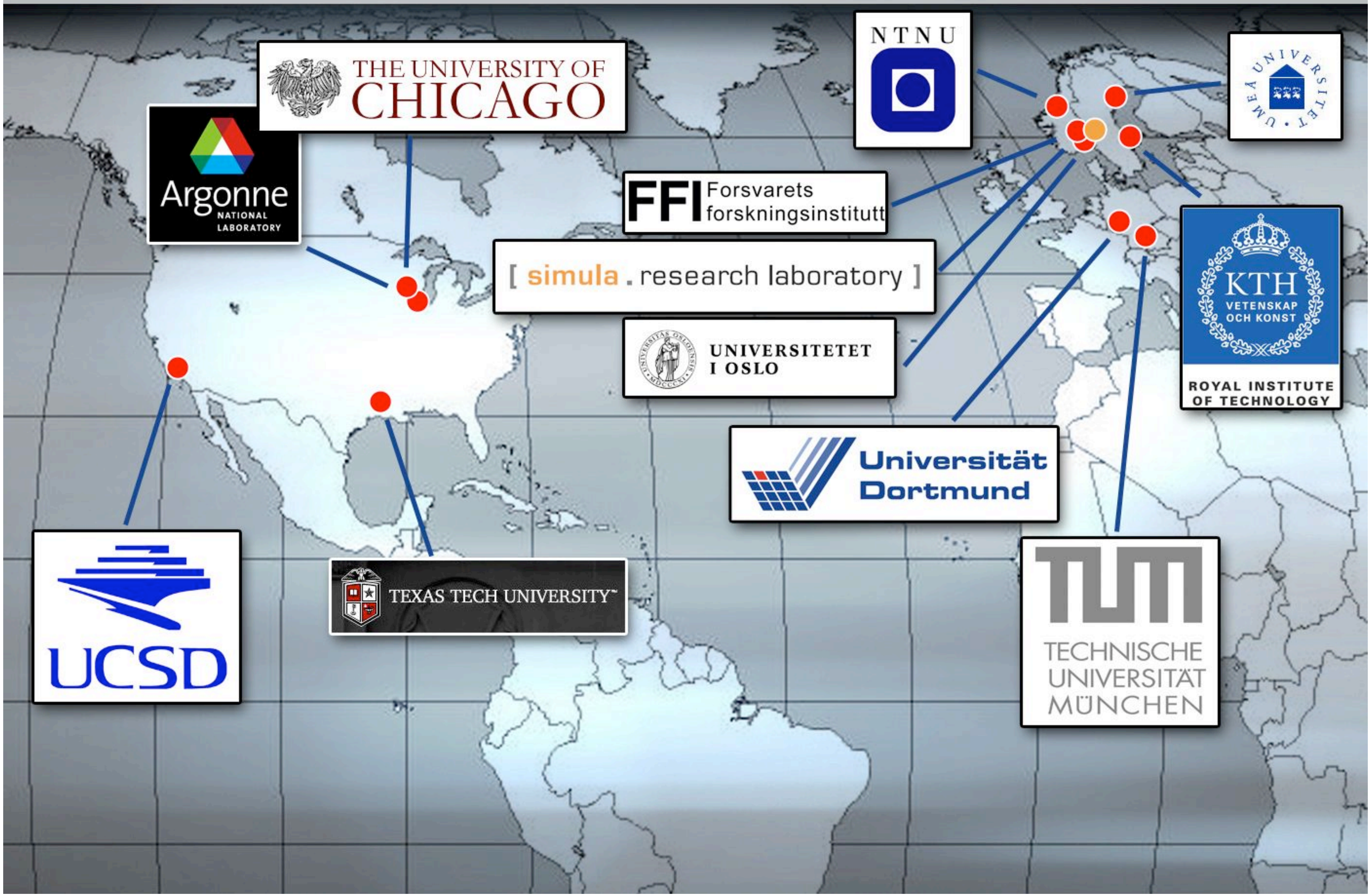

t = 0
while t <= T:
e at T=%g' % t)
if (efix .and. qr(i-1,1).lt.0.d0
& .and. ql(i,1).gt.0.d0) then
amdq(i,1) = -qr(i-1,
apdq(i,1) = ql(i,1)**
template <class _Tp, class _Allocator, bool _IsStatic>
public:
typedef typename _Alloc_traits<_Tp, _Allocator>::allo
allocator_type;
allocator_type get_allocator() const { return _Node_al
_List_alloc_base(const allocator_type& __a) : _Node_
#ifndef __NO_ARROW_OPERATOR
pointer operator->() const { return &(operator*()); } #e
M = G.compute_mass_matri
A = G.compute_stiffness_ma
B = G.compute_div_matrix(v
D = G.compute_stiffness_ma
T = 1; dt = 0.1
while t < T:
t = t + dt
f = G.compute_source_vector(rhs)
C = G.compute_convection_matrix(velo
A1 = M + dt*A + dt*C
prec1 = MLPrec(A1)
FLUENT
The Right Answer in CFD

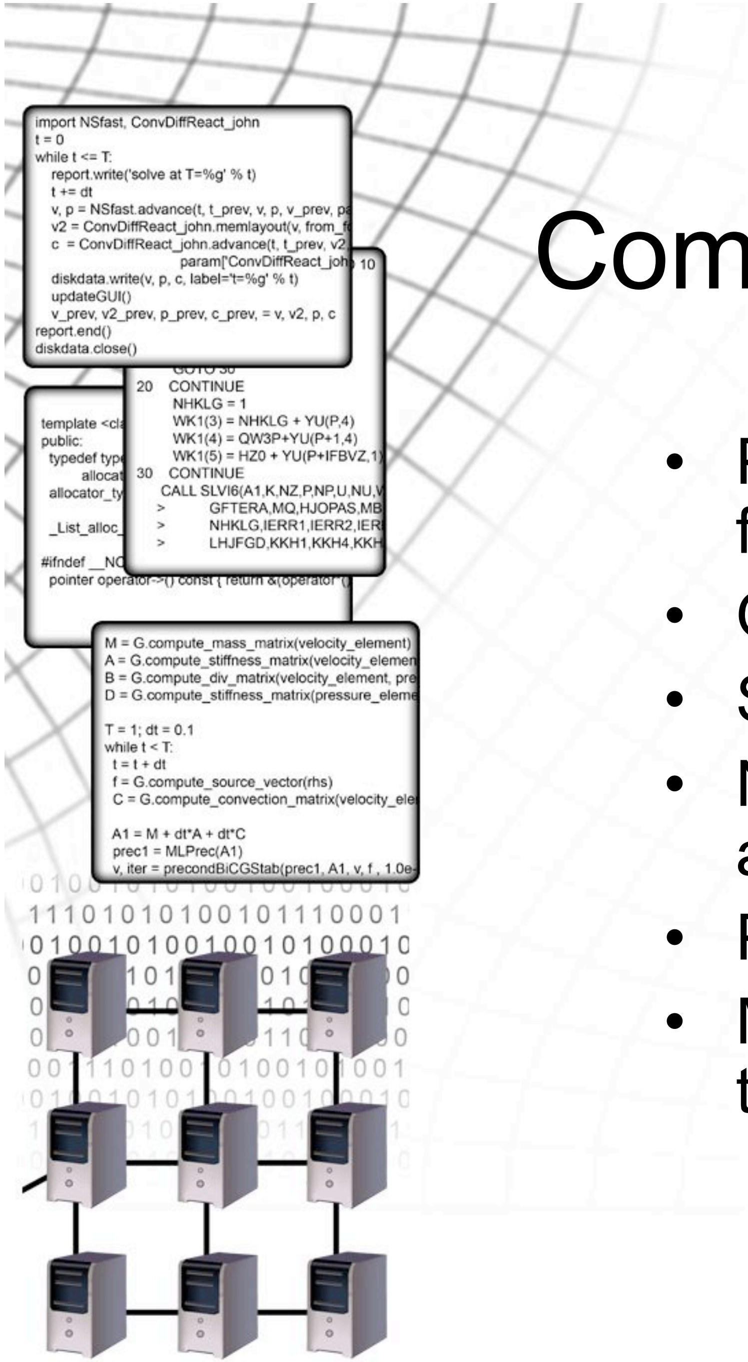


Three main parts

- Computational middleware
- Robust flow solvers
- Biomedical flow applications

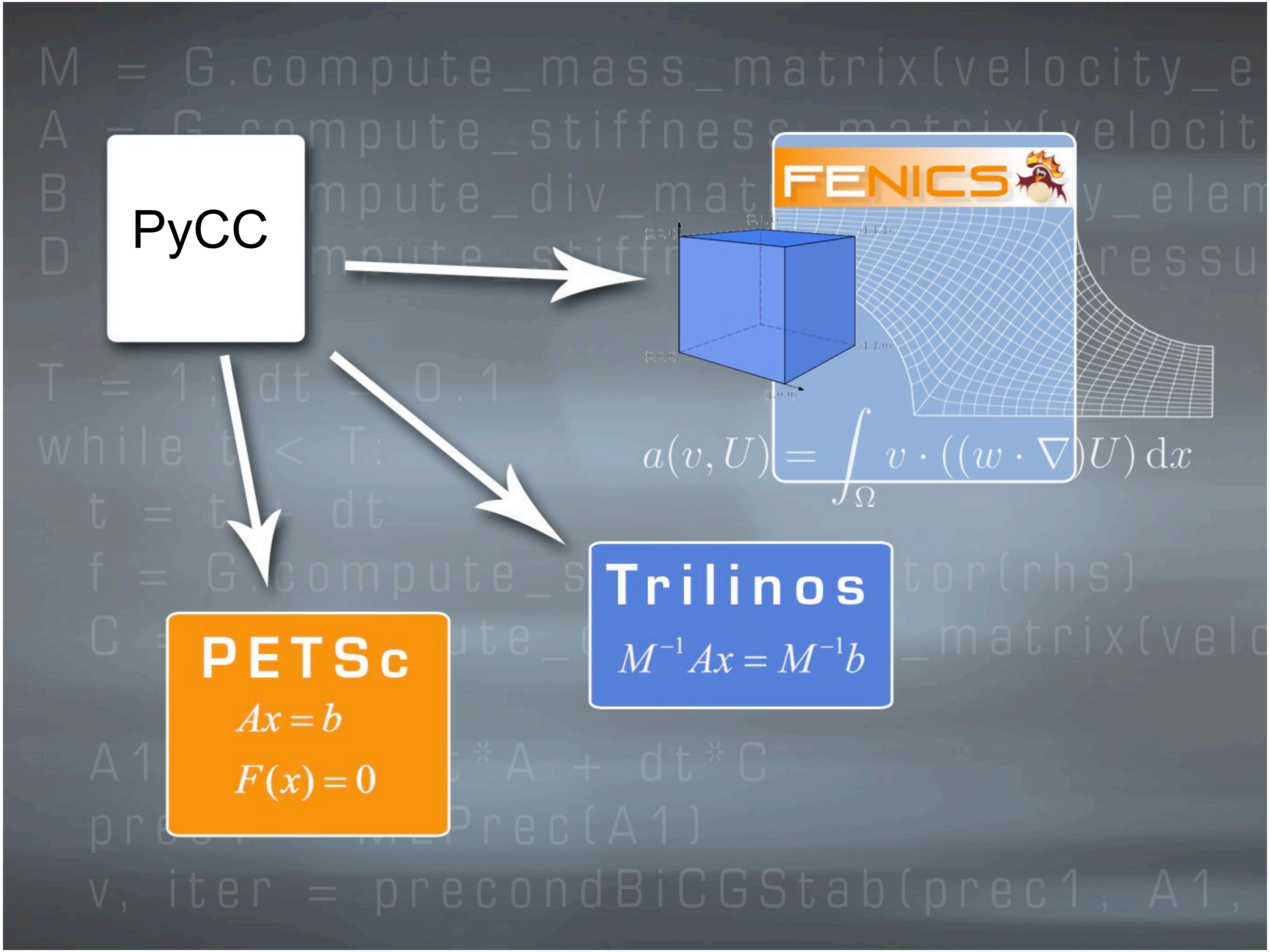
SOFTWARE COMPONENTS FOR BIOMEDICAL FLOWS

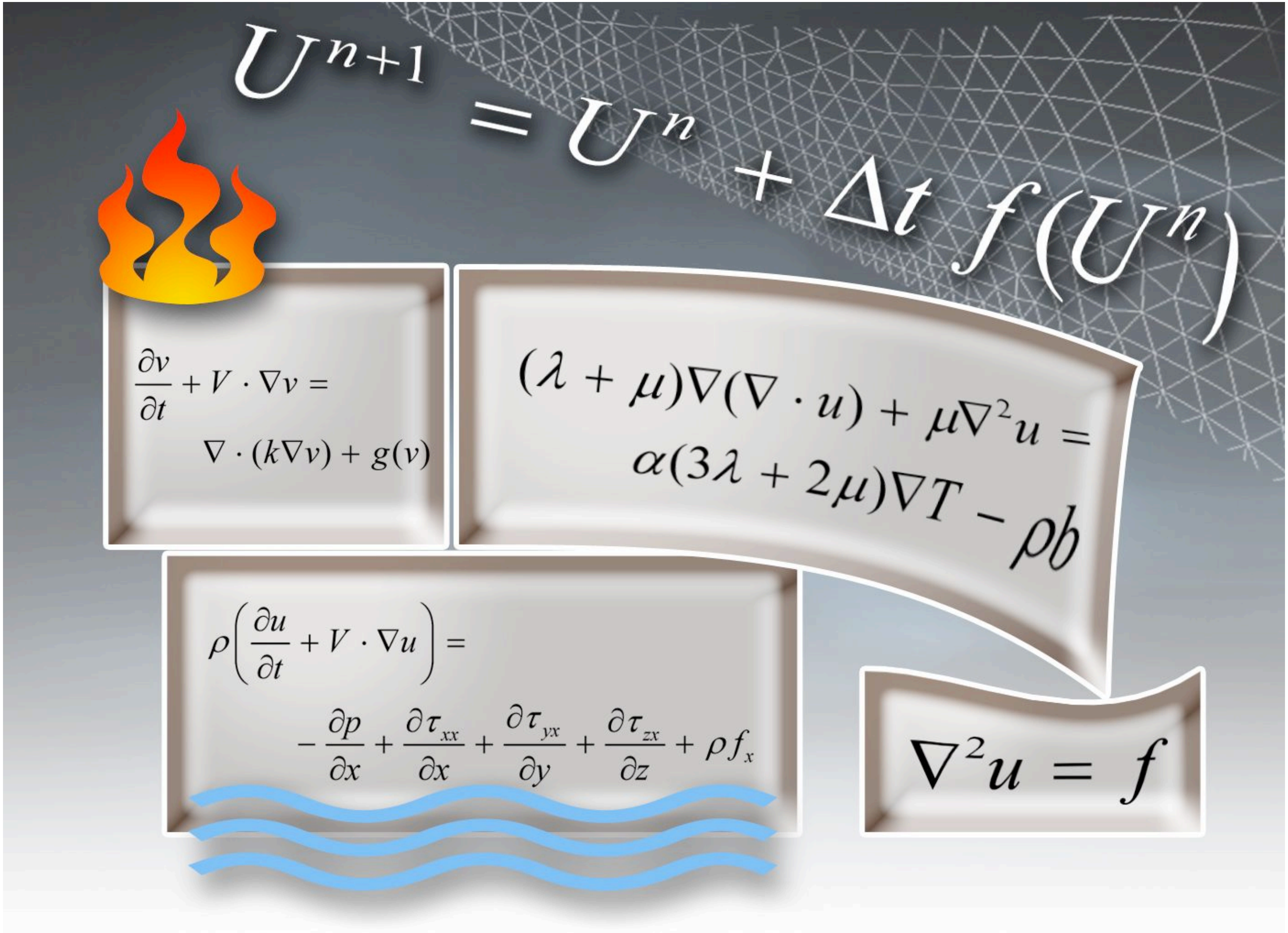




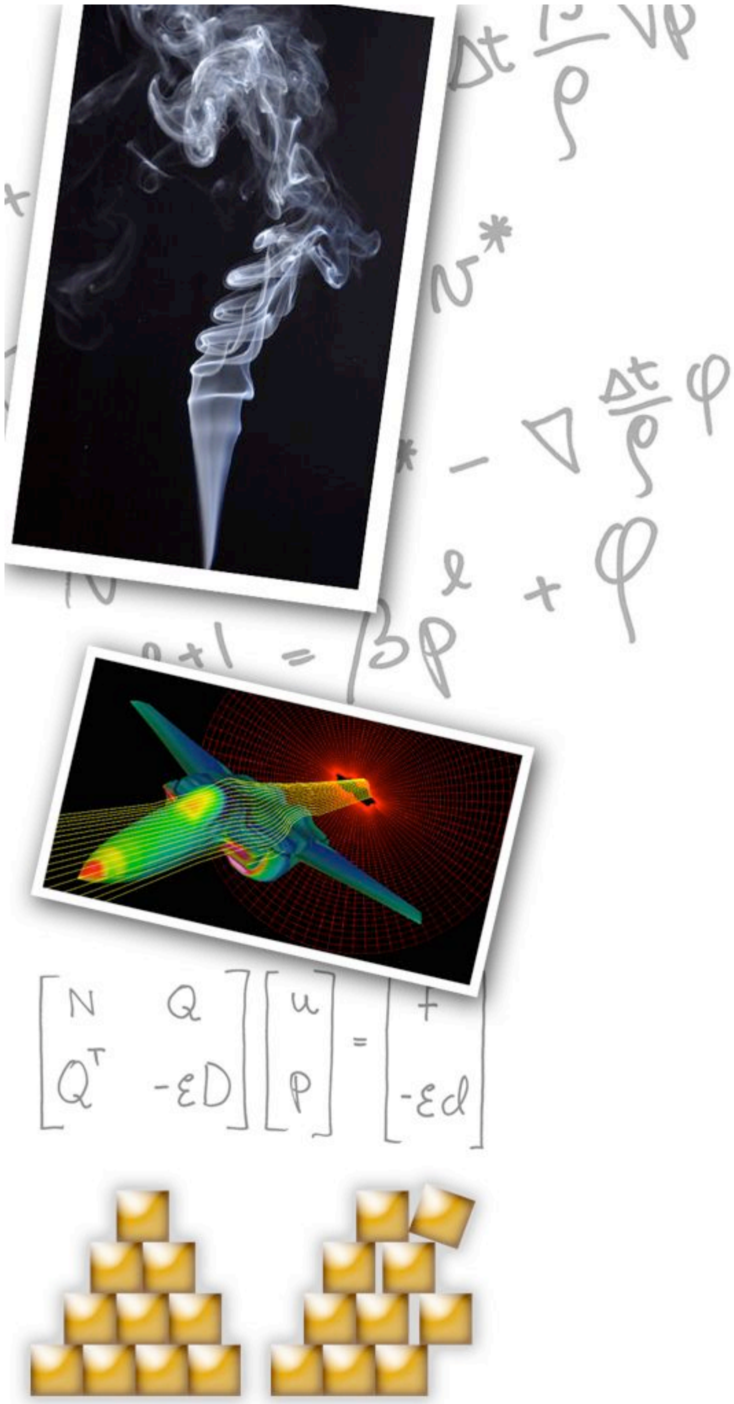
Computational middleware

- Problem solving environments for PDEs
- Old and modern libraries
- Stand-alone black-box codes
- New code (PyCC, FEniCS, automatically generated)
- Parallel computing
- Main focus: fluid flows, but the tools aim at ”any” PDE system


PyCC
FENICS
$a(v,U) = \int_\Omega v \cdot ((w \cdot \nabla) U) \, \mathrm{d}x$
PETSc
$Ax = b$
$F(x) = 0$
Trilinos
$M^{-1}Ax = M^{-1}b$

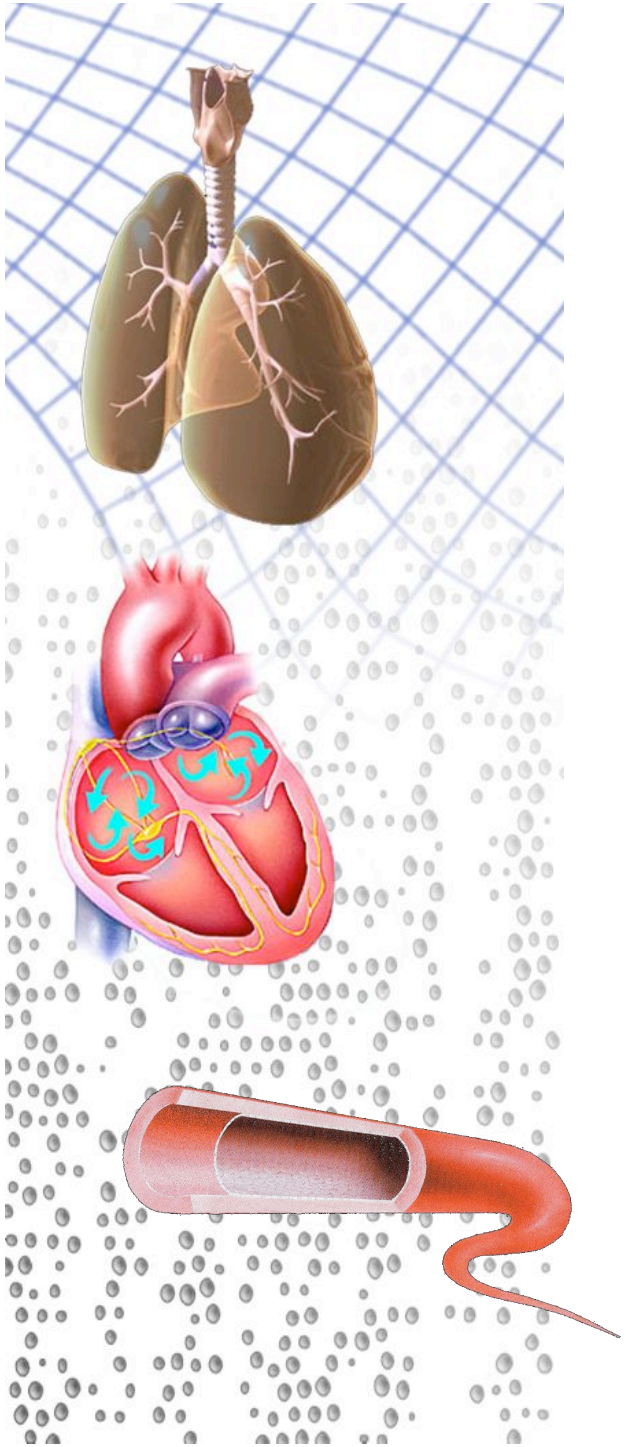


$U^{n+1} = U^n + \Delta t\, f(U^n)$
$\frac{\partial v}{\partial t} + V \cdot \nabla v = \nabla \cdot (k \nabla v) + g(v)$
$(\lambda + \mu)\nabla(\nabla \cdot u) + \mu \nabla^2 u = \alpha(3\lambda + 2\mu)\nabla T - \rho b$
$\rho\left(\frac{\partial u}{\partial t} + V \cdot \nabla u\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + \rho f_x$
$\nabla^2 u = f$



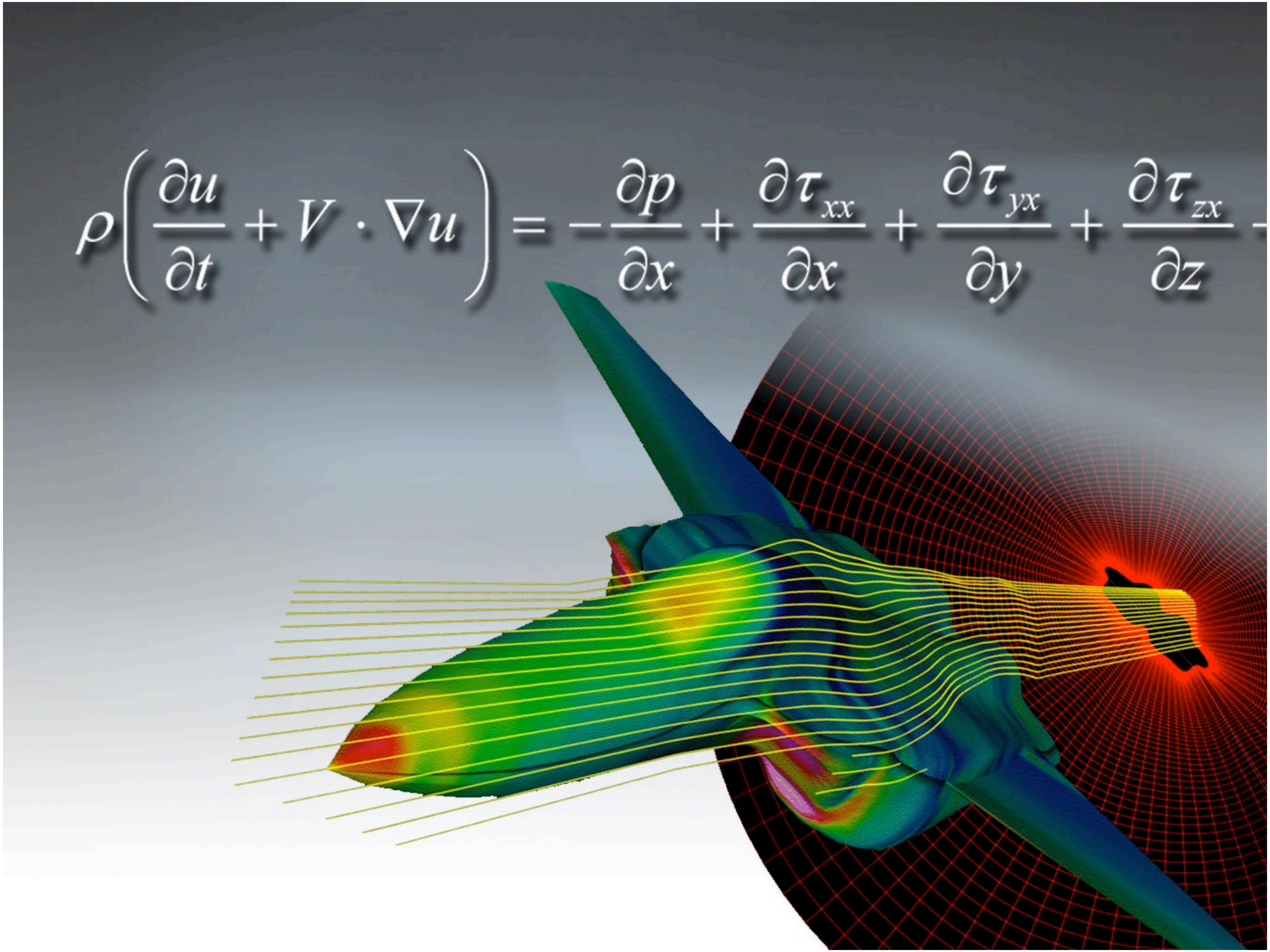
Robust flow solvers

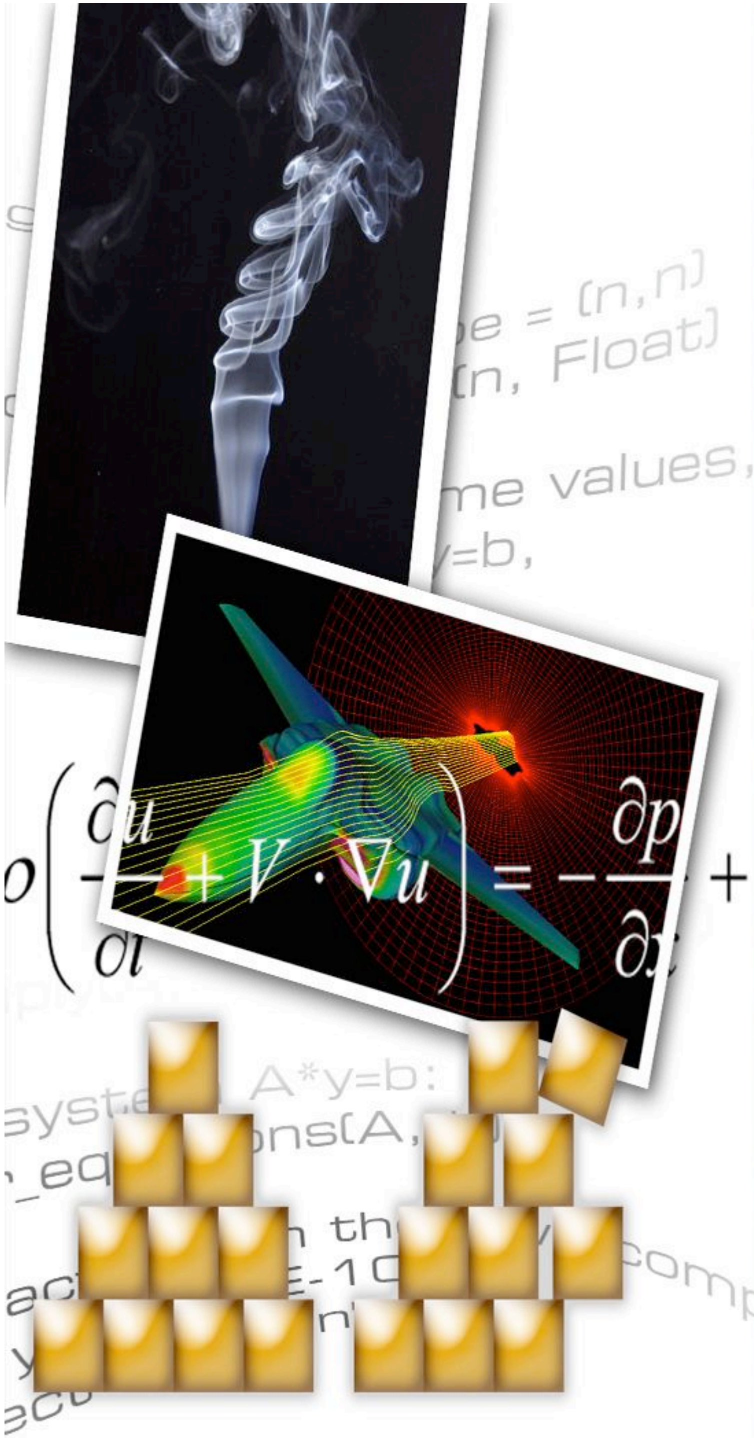
- Implicit methods
- Block preconditioning
- Fluid-structure interaction
- Error estimation
- Adaptivity
- Turbulence modeling & DNS
- Validation by lab. experiments

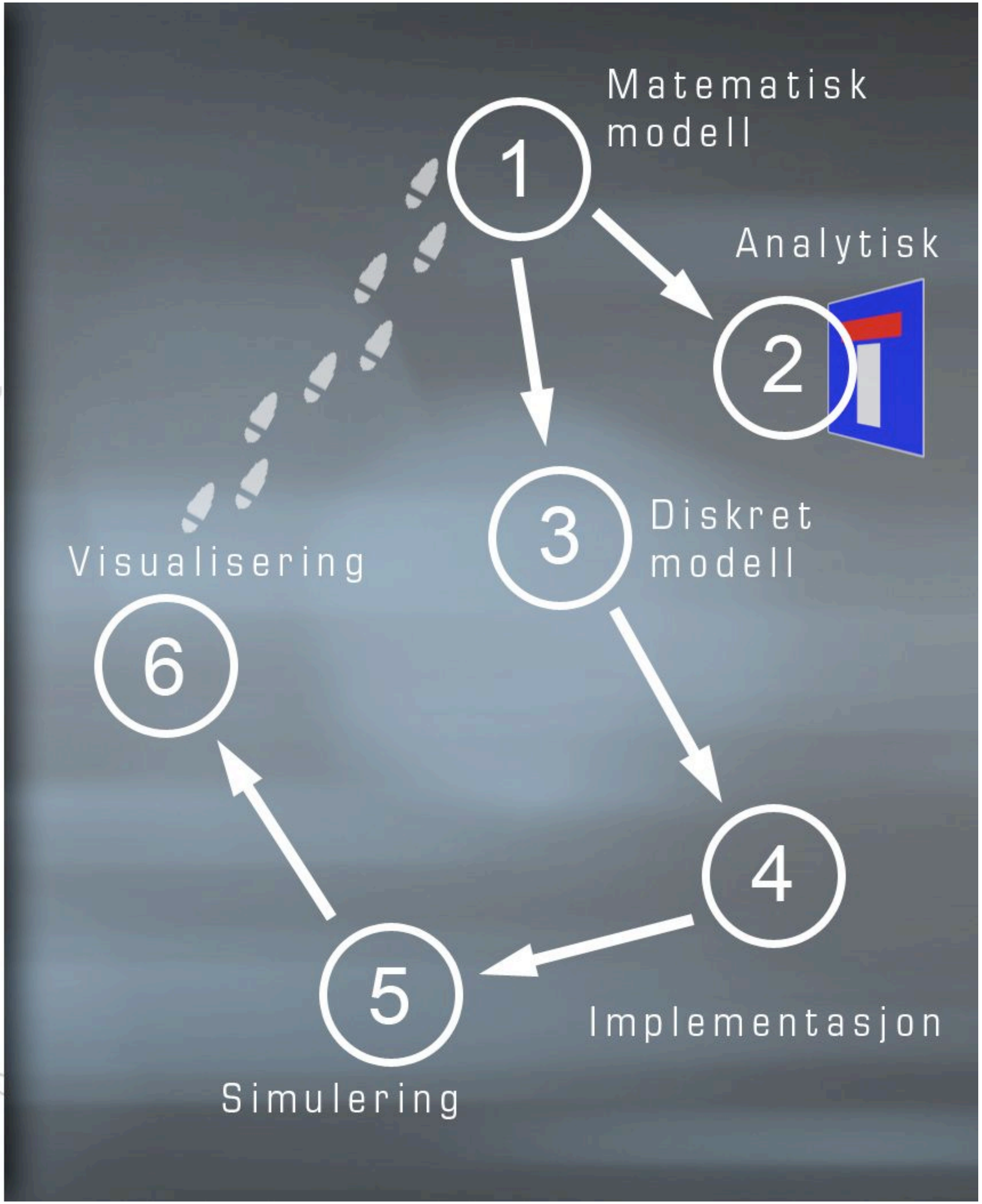


Biomedical flows

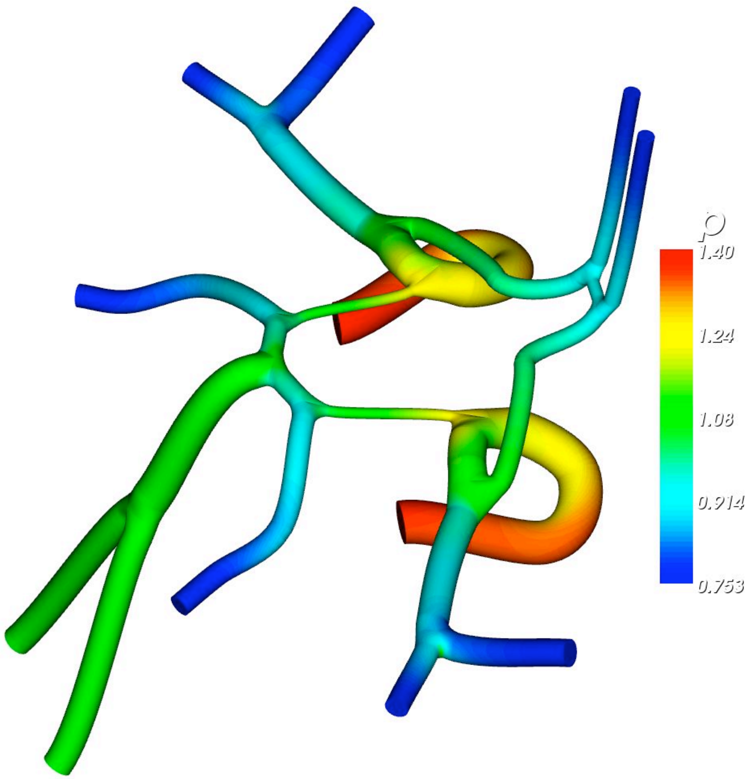
- Drug inhalation
- Aerosol flow (bacteria)
- Circle of Willis
- Fluid-structure interactions
- 1D arterial network
- Multiscale 1D-3D blood flow
- Tissue deformation
- Flow around the mitral valve in the heart
- Sound waves in the lungs
- Flow, deformation and electrophysiology in the heart
- Fundamental fluid mechanics research


$\rho\left(\frac{\partial u}{\partial t} + V \cdot \nabla u\right) = -\frac{\partial p}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z}$



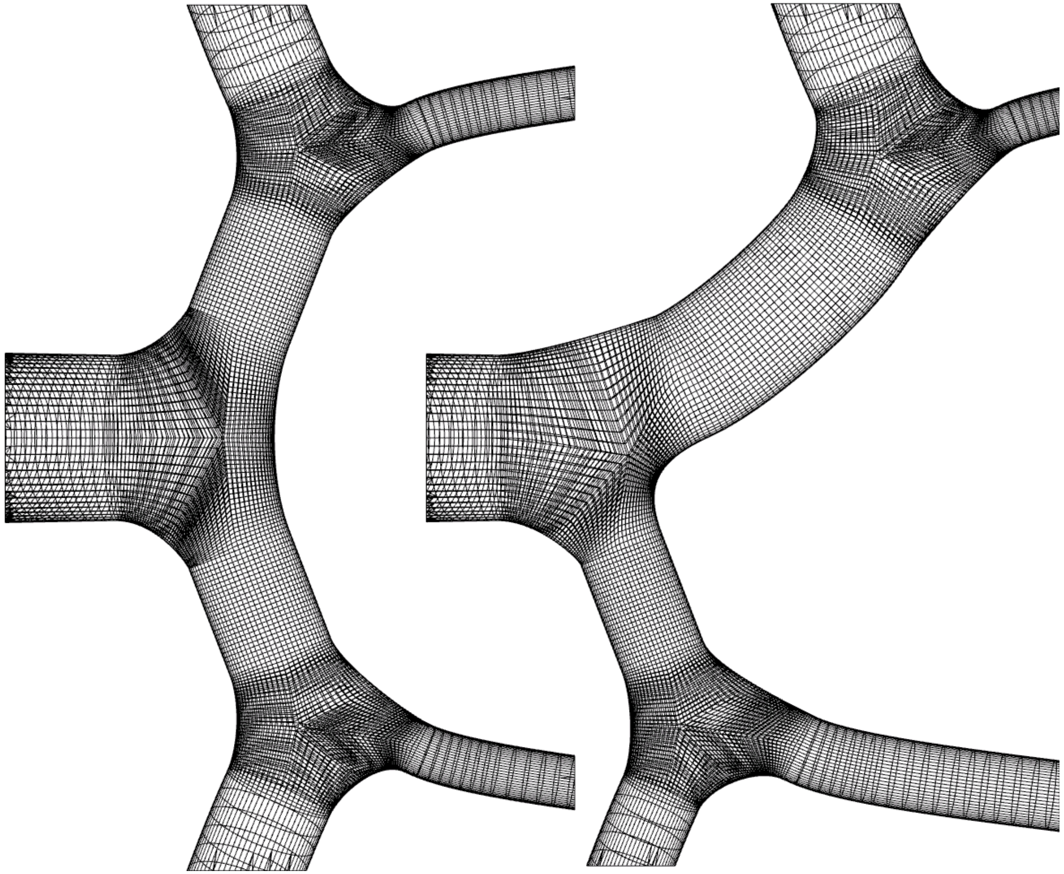

Matematisk
modell
1
Analytisk
2
3
Diskret
modell
Visualisering
6
4
5
Implementasjon
Simulering

Blood flow is incompressible, with Newtonian behaviour in large vessels



Using prescribed time varying flow rates on inlets, equal pressures on all outlets, and rigid vessel walls

Navier-Stokes equations are solved with the Finite Element Method, using Featflow



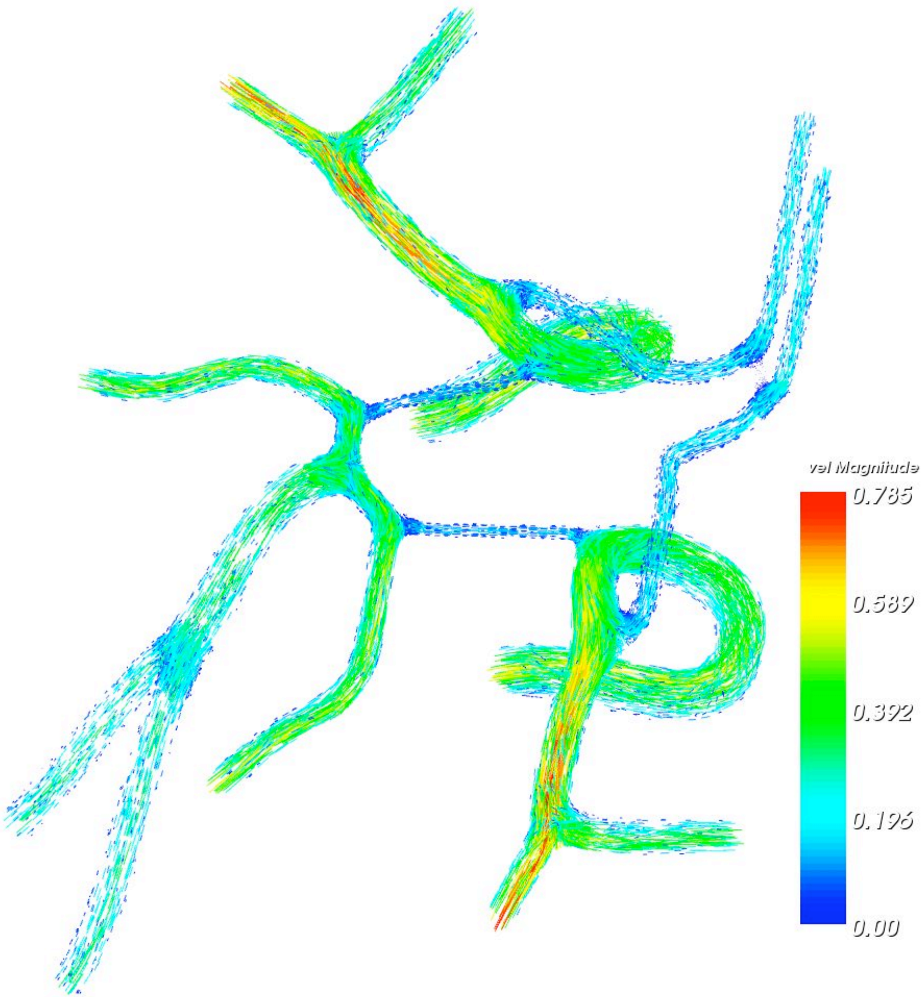
Grids are created from a parameterization, using custom written software

Simulation results on the full CoW geometry are within normal values found in medical studies

Only limited boundary data are available

The geometry is a simplification

Even so, the results seem realistic

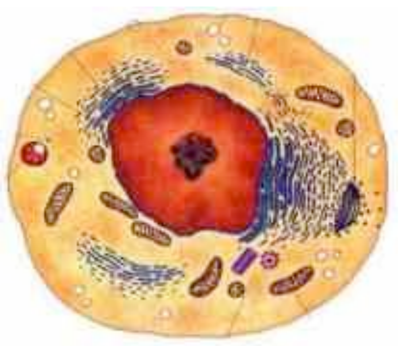


Other biomedical applications; cardiac electrophysiology

1. Complete simulator for heart electrophysiology and mechanics

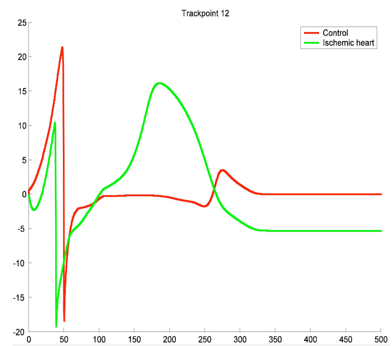
2. Automatic detection of ischemic heart disease based on ECG recordings

Celle



Komplett hjerte

EKG



Norwegian
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