

# Pseudo-code for CG routines and algorithms

Bill Henshaw

Centre for Applied Scientific Computing,  
Lawrence Livermore National Laboratory,  
henshaw@llnl.gov

February 5, 2016

## Contents

<b>1</b>	<b>Time-stepping pseudo code</b>	<b>2</b>
1.1	DomainSolver::advanceAdamsPredictorCorrector . . . . .	2
<b>2</b>	<b>Moving grid pseudo code</b>	<b>3</b>
2.1	DomainSolver::moveGrids . . . . .	3
2.2	MovingGrids::moveGrids . . . . .	3
2.3	MovingGrids::moveDeformingBodies . . . . .	3
<b>3</b>	<b>DeformingBodyMotion pseudo code</b>	<b>4</b>
3.1	DeformingBodyMotion::integrate . . . . .	4
3.2	DeformingBodyMotion::regenerateComponentGrids . . . . .	4
3.3	DeformingBodyMotion::correct . . . . .	4
<b>4</b>	<b>Cgmp</b>	<b>5</b>
4.1	Cgmp::solve . . . . .	5
4.2	Cgmp::multiDomainAdvance . . . . .	6
4.3	Cgmp::multiDomainAdvanceNew . . . . .	7
<b>5</b>	<b>Interfaces</b>	<b>8</b>
5.1	Cgmp::assignInterfaceRightHandSide . . . . .	8
5.2	DomainSolver::interfaceRightHandSide . . . . .	9

# 1 Time-stepping pseudo code

## 1.1 DomainSolver::advanceAdamsPredictorCorrector

Here is an overview of the DomainSolver::advanceAdamsPredictorCorrector function (cg/common/src/advancePC.bC) This is an explicit Adams predictor-corrector time stepper.

```
DomainSolver::advanceAdamsPredictorCorrector( ..., numberOfSubSteps, ..)
{
    initialize
    for( int mst=1; mst≤numberOfSubSteps; mst++ ) take time steps
        if adapt grids
            adaptGrids( ... )
        if move grids
            moveGrids( ... ); (Sec. 2.1)
            exposedPoints.interpolate(...)

        predictor step:
        getUt( ... )
        interpolateAndApplyBoundaryConditions( ... );
        solveForTimeIndependentVariables( ... )
        correctMovingGrids( ... )

    for( int correction=0; correction<numberOfCorrections; correction++ )
        corrector step:
        getUt( ... )
        solveForTimeIndependentVariables( ... )
        interpolateAndApplyBoundaryConditions( ... );
        correctMovingGrids( ... )
}
```

Figure 1: Pseudo-code outline of the advanceAdamsPredictorCorrector function.

## 2 Moving grid pseudo code

### 2.1 DomainSolver::moveGrids

Pseudo-code for DomainSolver::moveGrids (cg/common/src/move.C)

```
DomainSolver::moveGrids( t1,t2,t3,dt0, cgf1,cgf2,cgf3 )
{
    setInterfacesAtPastTimes( t1,t2,t3,dt0,cgf1,cgf2,cgf3 ); initialize interfaces
    parameters.dbase.get<MovingGrids>("movingGrids").moveGrids(t1,t2,t3,dt0,cgf1,cgf2,cgf3 );
    gridGenerator->updateOverlap( cg, mapInfo ); regenerate the grid with Ogen
}
```

### 2.2 MovingGrids::moveGrids

Pseudo-code for MovingGrids::moveGrids (cg/common/moving/src/MovingGrids.C)

```
MovingGrids::moveGrids( t1,t2,t3,dt0, cgf1,cgf2,cgf3 )
{
    First move the bodies (but not the grids):
    detectCollisions(cgf1);
    rigidBodyMotion( t1,t2,t3,dt0,cgf1,cgf2,cgf3 );
    moveDeformingBodies( t1,t2,t3,dt0,cgf1,cgf2,cgf3 );
    userDefinedMotion( t1,t2,t3,dt0,cgf1,cgf2,cgf3 );
    Apply any matrix motions: rotate, shift, scale

    getGridVelocity( cgf2,t2 );
    Now move the grids:
    for( grid=0; grid<numberOfBaseGrids; grid++ )
        MatrixTransform & transform = *cgf3.transform[grid];
        if( moveOption(grid)==matrixMotion )
            apply specified rotation and/or shift
            transform.rotate(...)
        else if( moveOption(grid)==rigidBody )
            rotate and shift the rigid body
            transform.rotate(...)
    for( int b=0; b<numberOfDeformingBodies; b++ )
        deformingBodyList[b]->regenerateComponentGrids( newT, cgf3.cg );

    getGridVelocity( cgf3,t3 );
}
```

### 2.3 MovingGrids::moveDeformingBodies

Pseudo-code for MovingGrids::moveDeformingBodies (cg/common/moving/src/MovingGrids.C)

```
MovingGrids::moveDeformingBodies( t1,t2,t3,dt0, cgf1,cgf2,cgf3 )
{
    for( int b=0; b<numberOfDeformingBodies; b++ )
        deformingBodyList[b]->integrate( t1,t2,t3,cgf1,cgf2,cgf3, stress);
}
```

### 3 DeformingBodyMotion pseudo code

The DeformingBodyMotion class handles deforming bodies.

#### 3.1 DeformingBodyMotion::integrate

Pseudo-code for DeformingBodyMotion::integrate (cg/common/moving/src/DeformingBodyMotion.C)  
This function is called by MovingGrids::movingGrids to move the deforming body (but not the grid associated with the deforming body).

```
MovingGrids::integrate( t1,t2,t3,dt0, cgf1,cgf2,cgf3, stress )
{
    if( elasticShell )
        advanceElasticShell(t1,t2,t3,cgf1,cgf2,cgf3,stress,option);
    else if( ... )

    for( int face=0; face<numberOfFaces; face++ )
        if( ... )
        else if( userDefinedDeformingBodyMotionOption==interfaceDeform )
            The deformed surface is obtained from the boundaryData array:
            RealArray & bd = parameters.getBoundaryData(side,axis,grid,cg[grid]);
            x0 = bd;
}
```

#### 3.2 DeformingBodyMotion::regenerateComponentGrids

Pseudo-code for DeformingBodyMotion::regenerateComponentGrids (cg/common/moving/src/DeformingBodyMotion.C)  
This function is called by MovingGrids::movingGrids (after calling DeformingBodyMotion::integrate) to actually generate the grid associated with the deforming body.

```
DeformingBodyMotion::regenerateComponentGrids( const real newT, CompositeGrid & cg)
{
    for( int face=0; face<numberOfFaces; face++ )
        hyp.generate(); Call the hyperbolic grid generator.
        Save the grid in the GridEvolution list:
        gridEvolution[face]->addGrid(dpm.getDataPoints(),newT);
}
```

#### 3.3 DeformingBodyMotion::correct

Pseudo-code for DeformingBodyMotion::correct (cg/common/moving/src/DeformingBodyMotion.C)  
This function is called by MovingGrids::correctGrids.

```
DeformingBodyMotion::correct( t1, t2, GridFunction & cgf1,GridFunction & cgf2 )
{
    This function currently does nothing.
}
```

## 4 Cgmp

### 4.1 Cgmp::solve

Pseudo-code for Cgmp::solve (cg/mp/src/solve.C)

```
Cgmp::solve()
{
    cycleZero();
    buildRunTimeDialog();
    for( int step=0; step<maximumNumberOfSteps && !finish; )
        if( t ≥ nextTimeToPrint )
            printTimeStepInfo(step,t,cpuTime);
            saveShow( gf[current] );
            finish=plot(t, optionIn, tFinal);
            if( finish ) break;
    dtNew = getTimeStep( gf[current] ); choose time step
    computeNumberOfStepsAndAdjustTheTimeStep(t,tFinal,nextTimeToPrint,numberOfSubSteps,dtNew);

    advance(tFinal); advance to t=nextTimeToPrint
}
```

## 4.2 Cgmp::multiDomainAdvance

Pseudo-code for Cgmp::multiDomainAdvance (cg/mp/src/multiDomainAdvance.C)

```
Cgmp::multiDomainAdvance( real &t, real &tFinal )
{
    if( initialize )
        initializeInterfaceBoundaryConditions( t,dt,gfIndex );
    ForDomain( d ) assignInterfaceRightHandSide( d, t, dt, correct, gfIndex );
    ForDomain( d ) domainSolver[d]->initializeTimeStepping( t,dt );
    Take some time steps:
    for( int i=0; i<numberOfSubSteps; i++ )
        ForDomain( d )
            domainSolver[d]->startTimeStep( t,dt,... );
            numberOfRequiredCorrectorSteps=...; gridHasChanged=...;
        if( gridHasChanged )
            initializeInterfaces(gfIndex); initializeInterfaceBoundaryConditions(...);

    for( int correct=0; correct<=numberOfCorrectorSteps; correct++ )
        ForDomain( d )
            assignInterfaceRightHandSide( d, t+dt, dt, correct, gfIndex ); (Sec. 5.1)
            domainSolver[d]->takeTimeStep( t,dt,correct,advanceOptions[d] );
            if( hasConverged = checkInterfaceForConvergence( .. ) ) break;

    ForDomain( d ) domainSolver[d]->endTimeStep( td,dt,advanceOptions[d] );
    t+=dt;
}
```

### 4.3 Cgmp::multiDomainAdvanceNew

Pseudo-code for Cgmp::multiDomainAdvanceNew (cg/mp/src/multiDomainAdvanceNew.bC). This is the new versio of the multi-domain advance routine that supports more general time stepping and the use of AMR.

```
Cgmp::multiDomainAdvanceNew( real &t, real &tFinal )
{
    if( initialize )
        initializeInterfaceBoundaryConditions( t,dt,gfIndex );
    ForDomain( d ) assignInterfaceRightHandSide( d, t, dt, correct, gfIndex );
    ForDomain( d ) domainSolver[d]->initializeTimeStepping( t,dt );
    Take some time steps:
    for( int i=0; i<numberOfSubSteps; i++ )
        ForDomain( d )
            domainSolver[d]->startTimeStep( t,dt,... );
            numberOfRequiredCorrectorSteps=...; gridHasChanged=...;
        if( gridHasChanged )
            initializeInterfaces(gfIndex); initializeInterfaceBoundaryConditions(...);
        Get current interface residual and save current interface values :
        getInterfaceResiduals( t, dt, gfIndex, maxResidual, saveInterfaceTimeHistoryValues );

        Stage I: advance the solution but do not apply BC's:
        ForDomain( d )
            assignInterfaceRightHandSide( d, t+dt, dt, correct, gfIndex );
            domainSolver[d]->takeTimeStep( t,dt,correct,step but no BC's );

        Stage II: Project interface values part 1:
        interfaceProjection( t+dt, dt, correct, gfIndex,set interface values );

        Stage III: evaluate the interface conditions and apply the boundary conditions:
        ForDomain( d )
            assignInterfaceRightHandSide( d, t+dt, dt, correct, gfIndex ); (Sec. 5.1)
            domainSolver[d]->takeTimeStep( t,dt,correct,apply BC's );

        Stage IV: Project interface values part 2:
        interfaceProjection( t+dt, dt, correct, gfIndex,set interface ghost values );

        if( hasConverged = checkInterfaceForConvergence( .. ) ) break;

    ForDomain( d ) domainSolver[d]->endTimeStep( td,dt,advanceOptions[d] );
    t+=dt;
}
```

## 5 Interfaces

### 5.1 Cgmp::assignInterfaceRightHandSide

The `Cgmp::assignInterfaceRightHandSide` function is used to get interface values from a source domain and set interface values on a target domain. It is used in the `Cgmp::multiDomainAdvance` routine [4.2](#).

Here is `Cgmp::assignInterfaceRightHandSide` (`cg/mp/src/assignInterfaceBoundaryConditions.C`)

```
int Cgmp::assignInterfaceRightHandSide( int d, real t, real dt, int correct, std::vector<int> &
gfIndex )
d : target domain, assign the interface RHS for this domain.
{
    if( interfaceList.size()==0 )
        initializeInterfaces(gfIndex); Create the list of interfaces.

    for( each interface on domain d )
        InterfaceDescriptor & interfaceDescriptor = interfaceList[inter];
        Target and source grid functions:
        GridFunction & gfTarget = domainSolver[domainTarget]->gf[gfIndex[domainTarget]];
        GridFunction & gfSource = domainSolver[domainSource]->gf[gfIndex[domainSource]];

        Get source data:
        for( int face=0; face<gridListSource.size(); face++ )
            domainSolver[domainSource]->interfaceRightHandSide( getInterfaceRightHandSide, ... );

        Transfer the source arrays to the target arrays:
        interfaceTransfer.transferData(... );

        Adjust the target data before assigning:
        for( int face=0; face<gridListTarget.size(); face++ )
            Extrapolate the initial guess.
            Under-relaxed iteration.

        Assign the target data:
        for( int face=0; face<gridListTarget.size(); face++ )
            domainSolver[domainTarget]->interfaceRightHandSide( setInterfaceRightHandSide,...);
}
```



## 5.2 DomainSolver::interfaceRightHandSide

The DomainSolver::interfaceRightHandSide function is used to get or set interface values. Each DomainSolver (cgad, cgcns, cgins, cgsm,...) has a version of this routine. The generic version appears in cg/common/src/interfaceBoundaryConditions.C.

Here is Cgcns::interfaceRightHandSide (cg/cns/src/interface.bC)

```
Cgcns::interfaceRightHandSide( InterfaceOptionsEnum option, int interfaceDataOptions,
    GridFaceDescriptor & info, GridFaceDescriptor & gfd, int gfIndex, real t )
{
    RealArray & bd = parameters.getBoundaryData(side,axis,grid,mg); Interface data on this domain.
    RealArray & f = *info.u; Interface data from another domain.

    if( interfaceType(side,axis,grid)==Parameters::heatFluxInterface )
        if( option==setInterfaceRightHandSide )
            bd(I1,I2,I3,tc)=f(I1,I2,I3,tc); Set T (using values from another domain).
        else if( option==getInterfaceRightHandSide )
            Evaluate  $a_0T + a_1T_n$  (to send to another domain).
            f(I1,I2,I3,tc) = a[0]*uLocal(I1,I2,I3,tc) + a[1]*( normal(I1,I2,I2,0)*ux + ... );

    else if( interfaceType(side,axis,grid)==Parameters::tractionInterface )
        if( option==setInterfaceRightHandSide )
            bd(I1,I2,I3,V)=f(I1,I2,I3,V); Set positions of the interface.
        else if( option==getInterfaceRightHandSide )
            parameters.getNormalForce( gf[gfIndex].u,traction,ipar,rpar );
            f(I1,I2,I3,V)=traction(I1,I2,I3,D);
            InterfaceDataHistory & idh = gfd.interfaceDataHistory; Holds interface history.
            if( interfaceDataOptions & Parameters::tractionRateInterfaceData )
                RealArray & f0 = idh.interfaceDataList[prev].f;
                f(I1,I2,I3,Vt)= (f(I1,I2,I3,V) - f0(I1,I2,I3,V))/dt; Time derivative of the traction.
}
```