Recent improvements to the 2/3—D imaging & inversion algorithms in the SLIM software release

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2D Code

Why?

Old code

- a lot of setup code duplicated across functions
  - only thing that changed was the actual PDE-dependent quantities

- parallelization + computation tied together
  - hard to debug
  - can’t easily extend to parallelizing over sources/sources + frequencies

Why?

Old code

- lots of manual tweaking to set up objective functions, GN Hessian
  - needless recomputation of wavefields

- lots of the same functionality being duplicated across functions
  - hard to maintain + integrate code changes over time

Old code structure

Helm2D.m - generates Helmholtz matrix

F.m - forward modeling kernel

DF.m - Jacobian + Jacobian adjoint of F.m

F.m - original

```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

% define wavelet
w = exp(1i*2*pi*model.freq*model.t0);
if model.f0
    % Ricker wavelet with peak-frequency model.f0
    w = (model.freq).^2.*exp(-(model.freq/model.f0).^2).*w;
end

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(1)));

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end

spmd
    codistr  = codistributor1d(2,[],[nsrc*nrec,nfreq]);
    freqloc  = getLocalPart(freq);
    wloc     = getLocalPart(w);
    nfreqloc = length(freqloc);
    Dloc     = zeros(nrec*nsrc,nfreqloc);
    if size(Q,3)==1
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Q));
            Dloc(:,k) = vec(Pr*Uk);
        end
    else
        Qloc = getLocalPart(Q);
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
            Dloc(:,k) = vec(Pr*Uk);
        end
    end
    D = codistributed.build(Dloc,codistr,'noCommunication');
end

% vectorize output, gather if needed
D = vec(D);

% construct pSPOT operator
J = oppDF(m,Q,model);
```


```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

% define wavelet
w = exp(1i*2*pi*model.freq*model.t0);
if model.f0
    % Ricker wavelet with peak-frequency model.f0
    w = (model.freq).^2.*exp(-(model.freq/model.f0).^2).*w;
end

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end
```


Setup code

- duplicated in DF.m

F.m - original

```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

% define wavelet
w = exp(1i*2*pi*model.freq*model.t0);
if model.f0
    % Ricker wavelet with peak-frequency model.f0
    w = (model.freq).^2.*exp(-(model.freq/model.f0).^2).*w;
end

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(1)));

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end

spmd
    codistr  = codistributor1d(2,[],[nsrc*nrec,nfreq]);
    freqloc  = getLocalPart(freq);
    wloc     = getLocalPart(w);
    nfreqloc = length(freqloc);
    Dloc     = zeros(nrec*nsrc,nfreqloc);
    if size(Q,3)==1
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Q));
            Dloc(:,k) = vec(Pr*Uk);
        end
    else
        Qloc = getLocalPart(Q);
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
            Dloc(:,k) = vec(Pr*Uk);
        end
    end
    D = codistributed.build(Dloc,codistr,'noCommunication');
end

% vectorize output, gather if needed
D = vec(D);

% construct pSPOT operator
J = oppDF(m,Q,model);
```


```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

% define wavelet
w = exp(1i*2*pi*model.freq*model.t0);
if model.f0
    % Ricker wavelet with peak-frequency model.f0
    w = (model.freq).^2.*exp(-(model.freq/model.f0).^2).*w;
end

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end
```


Complicated formula - do once + never again

- inhibits readability

F.m - first update

```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

% define wavelet
w = fwi_wavelet(model.freq,model.t0,model.f0);

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(1)));

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end

spmd
    codistr  = codistributor1d(2,[],[nsrc*nrec,nfreq]);
    freqloc  = getLocalPart(freq);
    wloc     = getLocalPart(w);
    nfreqloc = length(freqloc);
    Dloc     = zeros(nrec*nsrc,nfreqloc);
    if size(Q,3)==1
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Q));
            Dloc(:,k) = vec(Pr*Uk);
        end
    else
        Qloc = getLocalPart(Q);
        for k = 1:nfreqloc
            Hk  = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            Uk  = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
            Dloc(:,k) = vec(Pr*Uk);
        end
    end
    D = codistributed.build(Dloc,codistr,'noCommunication');
end

% vectorize output, gather if needed
D = vec(D);

% construct pSPOT operator
J = oppDF(m,Q,model);
```

```
% comp. grid
ot = model.o-model.nb.*model.d;
dt = model.d;
nt = model.n+2*model.nb;
[zt,xt] = odn2grid(ot,dt,nt);

% data size
nsrc   = size(Q,2);
nrec   = length(model.zrec)*length(model.xrec);
nfreq  = length(model.freq);

w = fwi_wavelet(model.freq,model.t0,model.f0);

% mapping from source/receiver/physical grid to comp. grid
Pr = opKron(opLInterp1D(xt,model.xrec),opLInterp1D(zt,model.zrec));
Ps = opKron(opLInterp1D(xt,model.xsrc),opLInterp1D(zt,model.zsrc));
Px = opKron(opExtension(model.n(2),model.nb(2)),opExtension(model.n(1),model.nb(

% model parameter: slowness [s/m] on computational grid.
nu = 1e-3*Px*sqrt(m);

% distribute frequencies according to standard distribution
freq = distributed(model.freq);
w    = distributed(w);

% check source matrix input
if (size(Q,3)==1)&&(isdistributed(Q))
    Q = gather(Q);
end
```

Complicated formula - make it a separate function

DF.m - original

```
if flag==1
    % solve Helmholtz for each frequency in parallel
    spmd
        codistr   = codistributor1d(2,codistributor1d.unsetPartition,[nsrc*nrec,nfreq]);
        freqloc   = getLocalPart(freq);
        wloc      = getLocalPart(w);
        nfreqloc  = length(freqloc);
        outputloc = zeros(nsrc*nrec,nfreqloc);

        if size(Q,3) == 1
            for k = 1: nfreqloc
                [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
                U0k       = Hk\(wloc(k)*(Ps'*Q));
                Sk        = -(2*pi*freqloc(k))*(dnu*(dHk*(U0k.*repmat(Px*input,1,nsrc))));
                U1k       = Hk\Sk;
                outputloc(:,k) = vec(Pr*U1k);
            end
        else
            Qloc = getLocalPart(Q);
            for k = 1: nfreqloc
                [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
                U0k       = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
                Sk        = -(2*pi*freqloc(k))*(dnu*(dHk*(U0k.*repmat(Px*input,1,nsrc))));
                U1k       = Hk\Sk;
                outputloc(:,k) = vec(Pr*U1k);
            end
        end
        output = codistributed.build(outputloc,codistr,'noCommunication');
    end
    output = vec(output);

else
    spmd
        freqloc   = getLocalPart(freq);
        wloc      = getLocalPart(w);
        nfreqloc  = length(freqloc);
        outputloc = zeros(prod(model.n),1);
        inputloc  = getLocalPart(input);

        if size(Q,3)==1
            for k = 1:nfreqloc
                inputloc  = reshape(inputloc,[nsrc*nrec,nfreqloc]);
                [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
                U0k       = Hk\(wloc(k)*(Ps'*Q));
                Sk        = -Pr'*reshape(inputloc(:,k),[nrec nsrc]);
                V0k       = Hk'\Sk;
                r         = (2*pi*freqloc(k))*real(sum(conj(U0k).*(dHk'*(dnu'*V0k)),2));
                outputloc = outputloc + Px'*r;
            end
        else
            Qloc = getLocalPart(Q);
            for k = 1:nfreqloc
                inputloc  = reshape(inputloc,[nsrc*nrec,nfreqloc]);
                [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
                U0k       = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
                Sk        = -Pr'*reshape(inputloc(:,k),[nrec nsrc]);
                V0k       = Hk'\Sk;
                r         = (2*pi*freqloc(k))*real(sum(conj(U0k).*(dHk'*(dnu'*V0k)),2));
                outputloc = outputloc + Px'*r;
            end
        end
        output = pSPOT.utils.global_sum(outputloc);
    end
    output = output{1};
end
```

```
% solve Helmholtz for each frequency in parallel
spmd
    codistr   = codistributor1d(2,codistributor1d.unsetPartition,[nsrc*nrec,nfreq
    freqloc   = getLocalPart(freq);
    wloc      = getLocalPart(w);
    nfreqloc  = length(freqloc);
    outputloc = zeros(nsrc*nrec,nfreqloc);

    if size(Q,3) == 1
        for k = 1: nfreqloc
            [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            U0k       = Hk\(wloc(k)*(Ps'*Q));
            Sk        = -(2*pi*freqloc(k))*(dnu*(dHk*(U0k.*repmat(Px*input,1,nsrc
            U1k       = Hk\Sk;
            outputloc(:,k) = vec(Pr*U1k);
        end
    else
        Qloc = getLocalPart(Q);
        for k = 1: nfreqloc
            [Hk, dHk] = Helm2D(2*pi*freqloc(k)*nu,ot,dt,nt,model.nb);
            U0k       = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
            Sk        = -(2*pi*freqloc(k))*(dnu*(dHk*(U0k.*repmat(Px*input,1,nsrc
            U1k       = Hk\Sk;
            outputloc(:,k) = vec(Pr*U1k);
        end
    end
    output = codistributed.build(outputloc,codistr,'noCommunication');
end
output = vec(output);
```

Doing basically the same thing, complicated formula

DF.m - first update

- if else branches for different cases
- matches the analytical formulas much closer
- still repeated code between F.m, DF.m
- even more repetition for Hessian functions

```
if flag==1
    input = Px*input;
    % solve Helmholtz for each frequency in parallel
    spmd
        codistr   = codistributor1d(2,codistributor1d.unsetPartition,[nsrc*nrec,nfreq]);
        freqloc   = getLocalPart(freq);
        wloc      = getLocalPart(w);
        nfreqloc  = length(freqloc);
        outputloc = zeros(nsrc*nrec,nfreqloc);
        if size(Q,3)>1
            Qloc = getLocalPart(Q);
        end

        for k=1:nfreqloc
            fm = f(m,freqloc(k));
            dfdm = df(m,freqloc(k)) .* input;

            % Hk = A * diag( (B*fm).^2 ) + const
            [Hk, A,B] = Helm2D(fm,ot,dt,nt,model.nb);

            % Derivative of mapping, fm -> Hk(fm)
            dHk = opMatrix(A)*opDiag((2*B*fm) .* (B*dfdm));

            if size(Q,3)==1
                U0k = Hk\(wloc(k)*(Ps'*Q));
            else
                U0k = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
            end

            % DU[dm] = H[m]\( -dH(m)[dm] * U(m) )
            Sk = -dHk * U0k;

            U1k = Hk\Sk;
            outputloc(:,k) = vec(Pr*U1k);
        end

        output = codistributed.build(outputloc,codistr,'noCommunication');
    end
    output = vec(output);

else
```

```
spmd
    codistr   = codistributor1d(2,codistributor1d.unsetPartition,[nsrc*nrec,nfreq
    freqloc   = getLocalPart(freq);
    wloc      = getLocalPart(w);
    nfreqloc  = length(freqloc);
    outputloc = zeros(nsrc*nrec,nfreqloc);

   if size(Q,3)>1
        Qloc = getLocalPart(Q);
    end

    for k=1:nfreqloc
        fm = f(m,freqloc(k));
        dfdm = df(m,freqloc(k)) .* input;

        % Hk = A * diag( (B*fm).^2 ) + const
        [Hk, A,B] = Helm2D(fm,ot,dt,nt,model.nb);

        % Derivative of mapping, fm -> Hk(fm)
        dHk = opMatrix(A)*opDiag((2*B*fm) .* (B*dfdm));

        if size(Q,3)==1
            U0k = Hk\(wloc(k)*(Ps'*Q));
        else
            U0k = Hk\(wloc(k)*(Ps'*Qloc(:,:,k)));
        end

        % DU[dm] = H[m]\( -dH(m)[dm] * U(m) )
        Sk = -dHk * U0k;

        U1k = Hk\Sk;
        outputloc(:,k) = vec(Pr*U1k);
    end
    output = codistributed.build(outputloc,codistr,'noCommunication');
end
output = vec(output);
```

Objective function - old way

```
function [f,g,h,w,f_aux] = misfit_red(m,Q,D,model,params)

[Dt,Jt] = F(m,Q,model);

D  = reshape(D, [nrec*nsrc,nfreq]);
Dt = reshape(Dt,[nrec*nsrc,nfreq]);

dR = D - Dt;

f = 0.5*norm(dR,'fro')^2;

if nargout > 1
    g = Jt'*vec(dR);
end

end
```

1 forward PDE solve

1 forward PDE re-solve, 1 adjoint PDE solve

Old code

Main components

- common setup code
  - helmholtz solving environment
  - model extension for PML, conversion from s^2/km^2 -> s/m
  - etc

- common computational code
  - forward wavefield solve
  - other wavefield solves, depending on what we need (forward modeling, forward jacobian, adjoint jacobian, hessian, gauss-newton hessian, LS objective)

New code

If you have a lot of duplication -> consolidation

PDEfunc.m

- general function for computing various quantities depending on Helmholtz solutions for FWI
  - forward model, migration, demigration, hessian, gauss-newton hessian, least squares objective + gradient
- options for solving PDEs iteratively, with LU, backslash

New code

If you have a lot of duplication -> consolidation

PDEfunc.m

- **additive** function over sources + receivers
- **serial** function intended to be run on each Matlab worker

Example - F.m, new code

```
if exist('params','var')==0, params = []; end

J = oppDF(m,Q,model,params);

freq = distributed(model.freq);
nsrc = length(model.xsrc); nrec = length(model.xrec); nfreq = length(model.freq);

spmd,
    [fStart,fEnd] = globalIndices(freq,2);
    model_loc = model;
    model_loc.freq = model_loc.freq(fStart:fEnd);
    Dloc = PDEfunc('forw_model',m,Q, [],[], model_loc, params);
    codist_f = getCodistributor(freq);
    codist = codistributor1d(2,codist_f.Partition,[nsrc*nrec,nfreq]);
    D = codistributed.build(Dloc,codist);
end

D = vec(D);
```

New code

For WRI

```
varargout = PDEfunc_wri( func, m, Q, dm, D, model, params);
```

Additional required options:

```
params.lambda - WRI lambda parameter
```

Check the documentation for more details

Code organization

F.m - forward modeling

oppDF.m - migration/demigration

oppH.m - Hessian
oppHGN.m - GN Hessian

PDEfunc - main setup, driver code

Benefits of new code

Single function where heavy computation is done

- any future optimizations to PDE solves propagate to entire code base

Separation of computation, parallelization

- can split up data in arbitrary ways without affecting the result, easier to test + show correctness

Benefits of new code

Now we have

- Gauss-Newton Hessian for FWI with no unnecessary PDE solves
- Full Hessian for FWI
- Gauss-Newton, Full Hessian for WRI
- All tested with correct Taylor error, adjoint test behaviour, so you know that they're actually correct

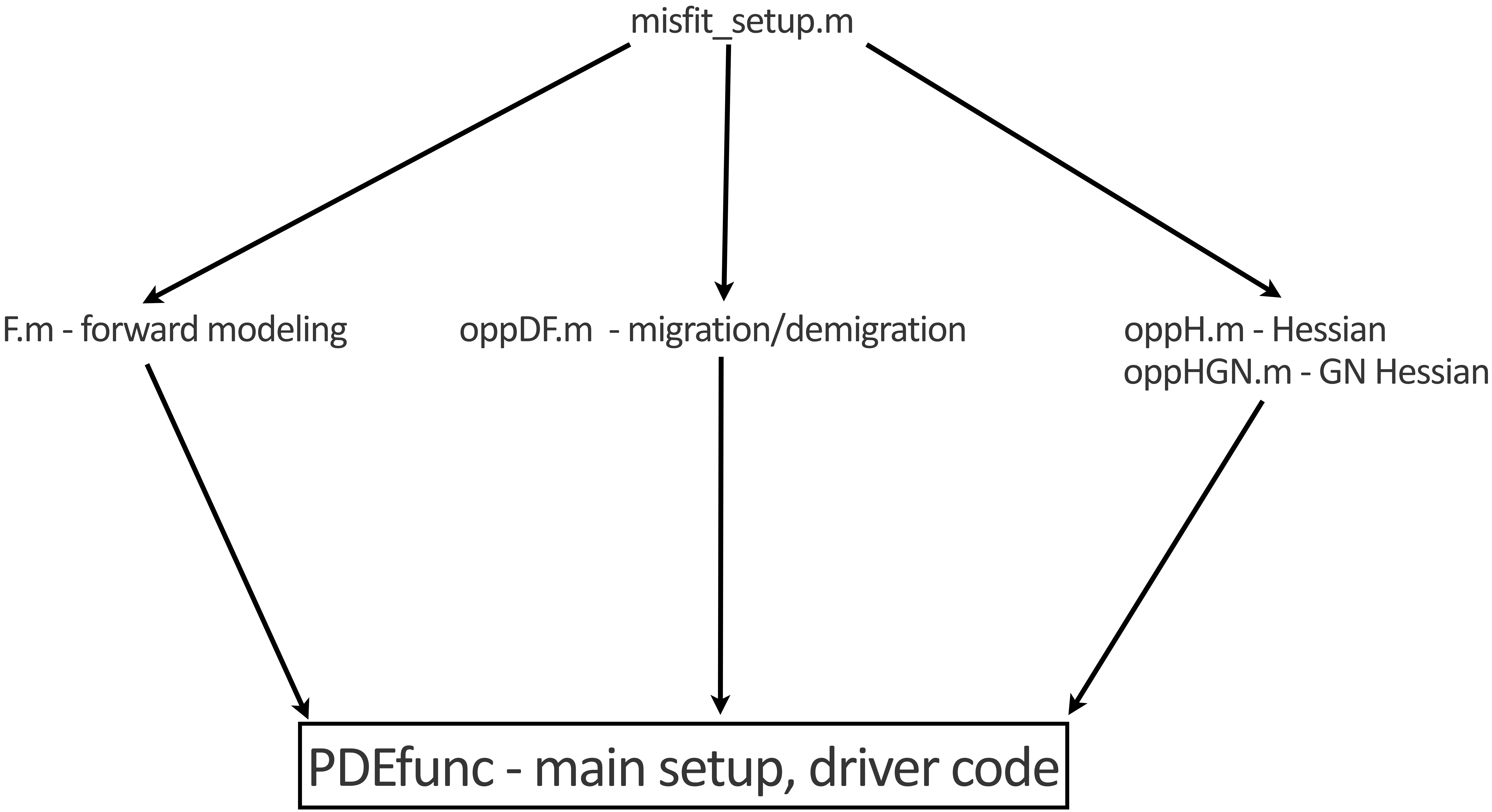
New code

You don't have to interact directly with PDEfunc, PDEfunc_wri

- F.m, oppDF.m, oppH.m, oppHGN.m just implement the parallelization over frequencies, use PDEfunc as their main driving code

Instead, there is the misfit_setup.m function for generating least-squares FWI, WRI objectives

Code organization



New code example - easy frequency continuation

Parallel over frequencies (default)

```
params.wri = false;                    %FWI objective
%params.dist_mode = ‘freq’;            %distribute over frequencies
freq_batch = {1:2,3:4,5:6,7:8};
mk = m0;

for j=1:length(freq_batch)
    params.freq_index = freq_batch{j}; %frequency selection
    obj_fwi = misfit_setup(Q,Dobs,model,params);
    mk = minFunc(obj_fwi,mk,opts);
end
```

New code example - easy frequency continuation

Parallel over sources

```
params.wri = false;                    %FWI objective
params.dist_mode = ‘src’;              %distribute over sources
freq_batch = {1:2,3:4,5:6,7:8};
mk = m0;

for j=1:length(freq_batch)
    params.freq_index = freq_batch{j};
    obj_fwi = misfit_setup(Q,Dobs,model,params);
    mk = minFunc(obj_fwi,mk,opts);
end
```

New code example - easy frequency continuation

Parallel over sources + frequencies

```
params.wri = false;                  %FWI objective
params.dist_mode = 'srcfreq';        %distribute over sources +
                                      frequencies

freq_batch = {1:2,3:4,5:6,7:8};
mk = m0;

for j=1:length(freq_batch)
    params.freq_index = freq_batch{j};
    obj_fwi = misfit_setup(Q,Dobs,model,params);
    mk = minFunc(obj_fwi,mk,opts);
end
```

New code example - easy frequency continuation

Parallel over frequencies

```
params.wri = true;                  %WRI objective
params.lambda = 10;                 %WRI penalty parameter
%params.hessian = ‘sparse’;         %sparse hessian for WRI,
                                    default

freq_batch = {1:2,3:4,5:6,7:8};
mk = m0;

for j=1:length(freq_batch)
    params.freq_index = freq_batch{j};
    obj_wri = misfit_setup(Q,Dobs,model,params);
    mk = minFunc(obj_wri,mk,opts);
end
```

New code example - easy frequency continuation

Parallel over frequencies

```
params.wri = true;                 %WRI objective
params.lambda = 10;                %WRI penalty parameter
params.hessian = ‘gn’;             %GN Hessian for WRI
freq_batch = {1:2,3:4,5:6,7:8};
mk = m0;

for j=1:length(freq_batch)
    params.freq_index = freq_batch{j};
    obj_wri = misfit_setup(Q,Dobs,model,params);
    mk = minFunc(obj_wri,mk,opts);
end
```

Summary

New code is

- modular and maintainable
  - parallelization, computation separated
  - easier to test, also passes tests
- easy to set up objectives + hessians for FWI/WRI
  - no unnecessary PDE solves
  - choice of modes of distributing data, not just over frequencies
- found in /tools/algorithms/
  - /2DFreqModeling - FWI
  - /WRI - WRI

3D Code

3D Modeling and Inversion

NEW 27 point stencil Helmholtz implementation

NEW linear system solvers

NEW multigrid-based preconditioner

All work by Rafael Lago

3D Modeling and Inversion

NEW 27 point stencil Helmholtz implementation

in /tools/algorithms/3DFreqModeling

- as little as 4 points per wave-length needed to stably invert the Helmholtz equation
- compared to ~10 points per wave-length of the standard 7 point stencil

SLIM

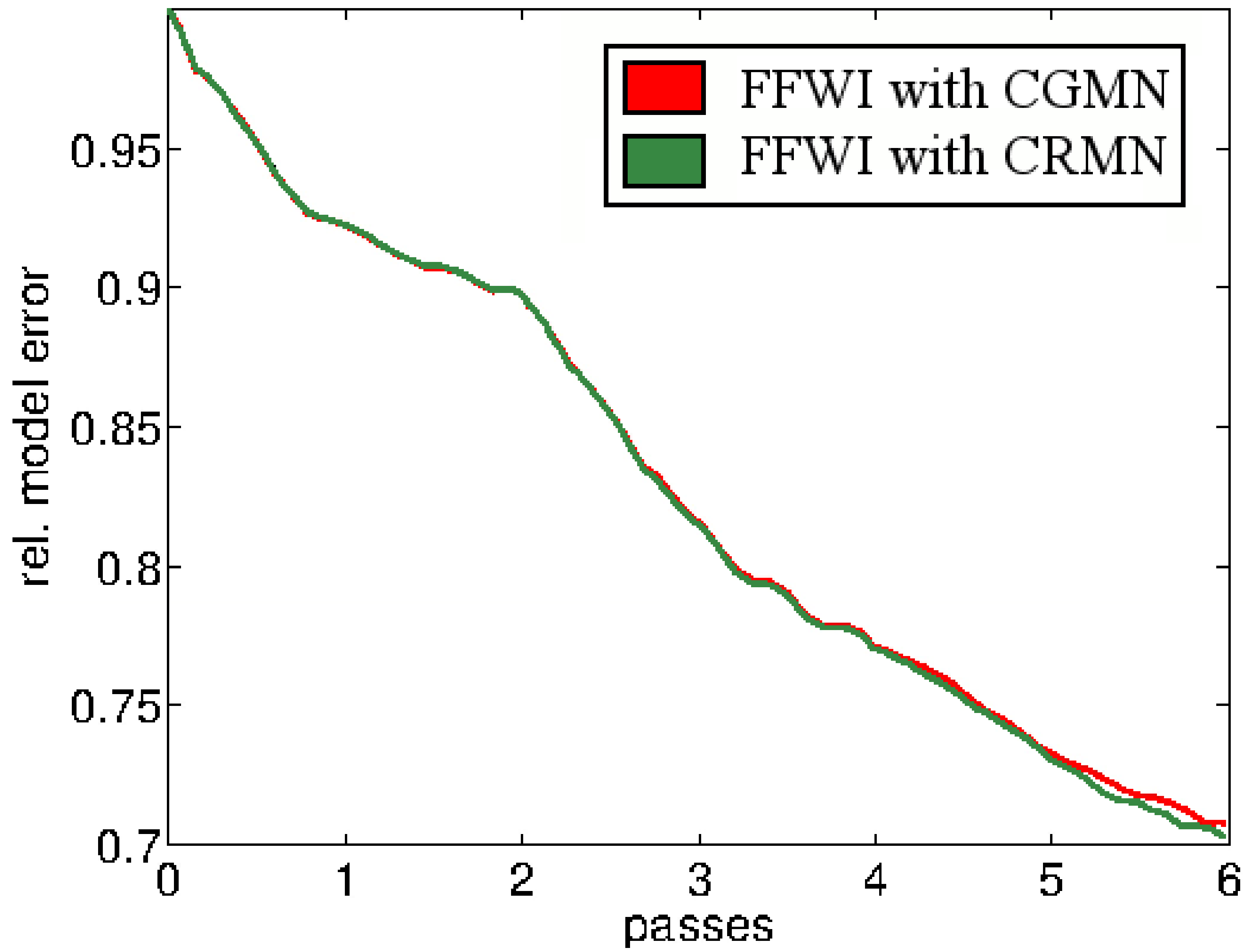
3D Modeling and Inversion

NEW linear system solvers

/tools/solvers/Krylov

- CGMN - CG preconditioned w/ double Kaczmarz sweeps
- CRMN - CR preconditioned w/ double Kaczmarz sweeps
- FGMRES - flexible GMRES, for use with the new preconditioner

3D Modeling and Inversion



PDE solver iterations

	FFWI with CGMN	FFWI with CRMN	Speedup
4 *Hz*	23,403	19,846	18%
6 *Hz*	30,189	24,387	24%
8 *Hz*	34,724	26,265	32%
Total	88,316	70,498	25%

Frugal FWI with a fixed number of PDE solves per frequency
Loose PDE tolerance at early iterations, tightens as iterations proceed

[1] Calandra, H., Gratton, S., Pinel, X. and Vasseur, X. [2013] An improved two-grid preconditioner for the solution of three-dimensional Helmholtz problems in heterogeneous media.

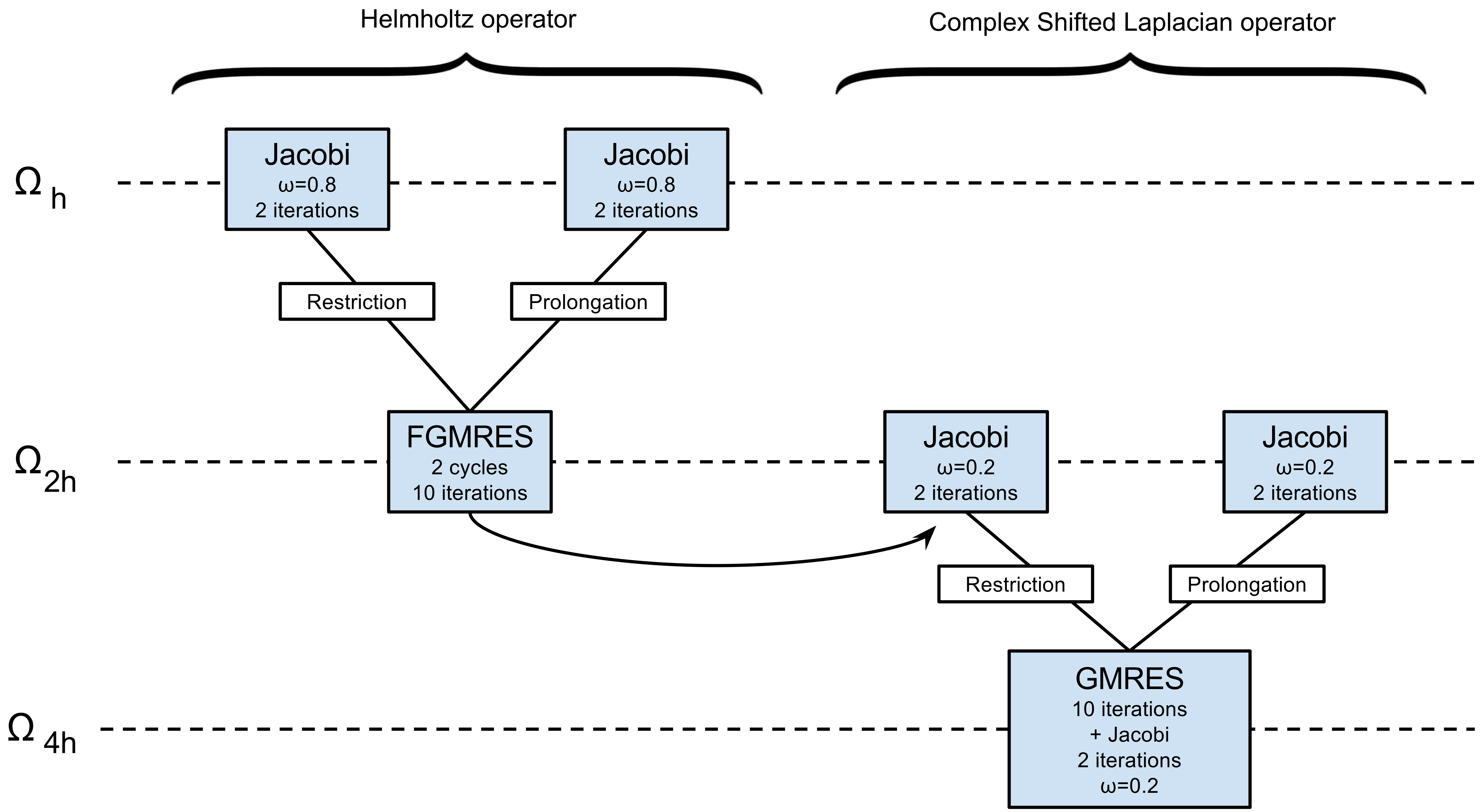
3D Modeling and Inversion

NEW multigrid-based preconditioner

in /tools/solvers/Multigrid

Extends previous work in [1] for a multigrid, shifted-Laplacian approach for a 7-point stencil to the 27-point case

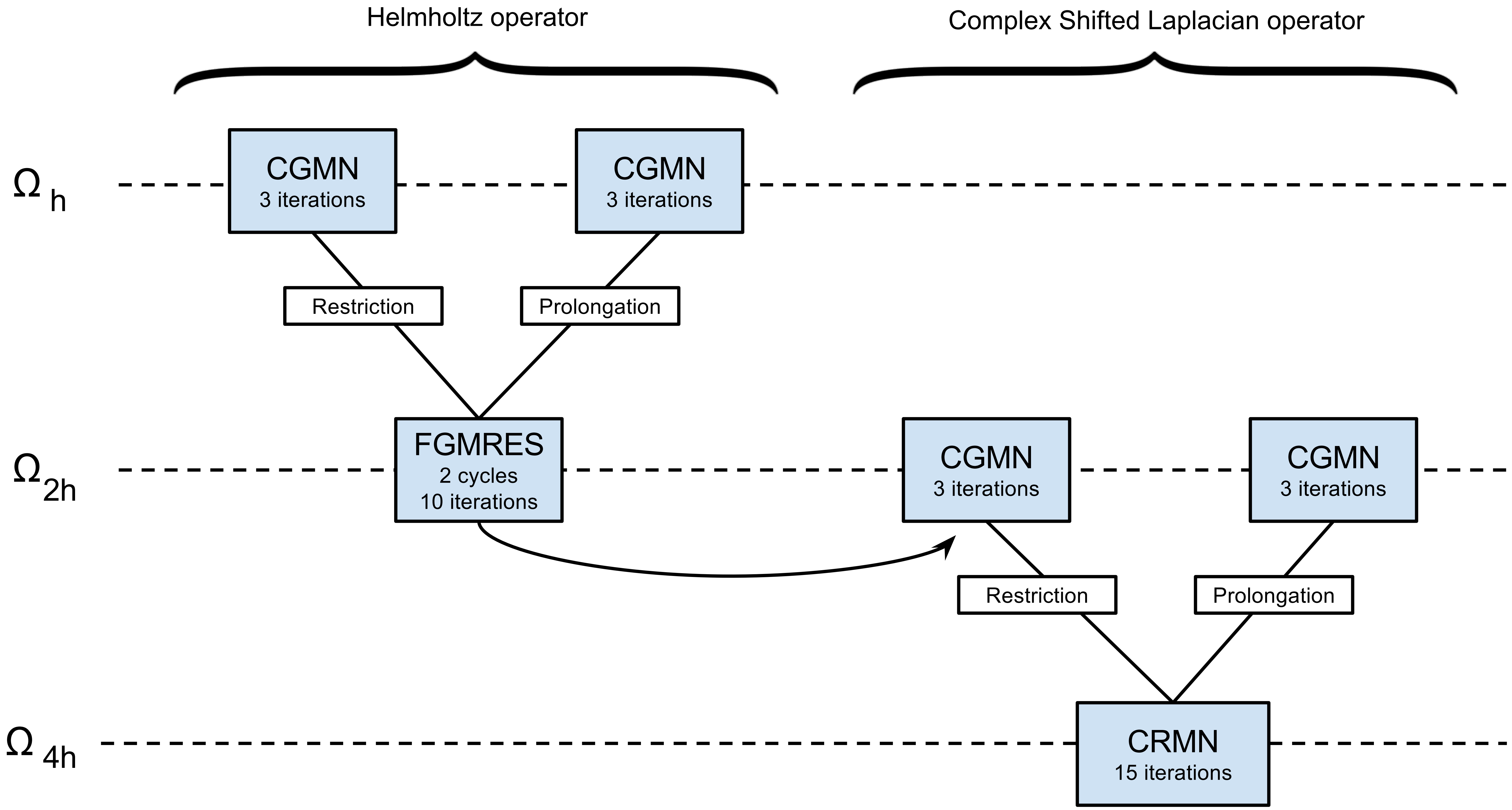
3D Modeling and Inversion



Preconditioner of [1]
Only works for 7 point stencil

[1] Calandra, H., Gratton, S., Pinel, X. and Vasseur, X. [2013] An improved two-grid preconditioner for the solution of three-dimensional Helmholtz problems in heterogeneous media.

3D Modeling and Inversion



New preconditioner

Works with 27 point stencil

3D Modeling and Inversion

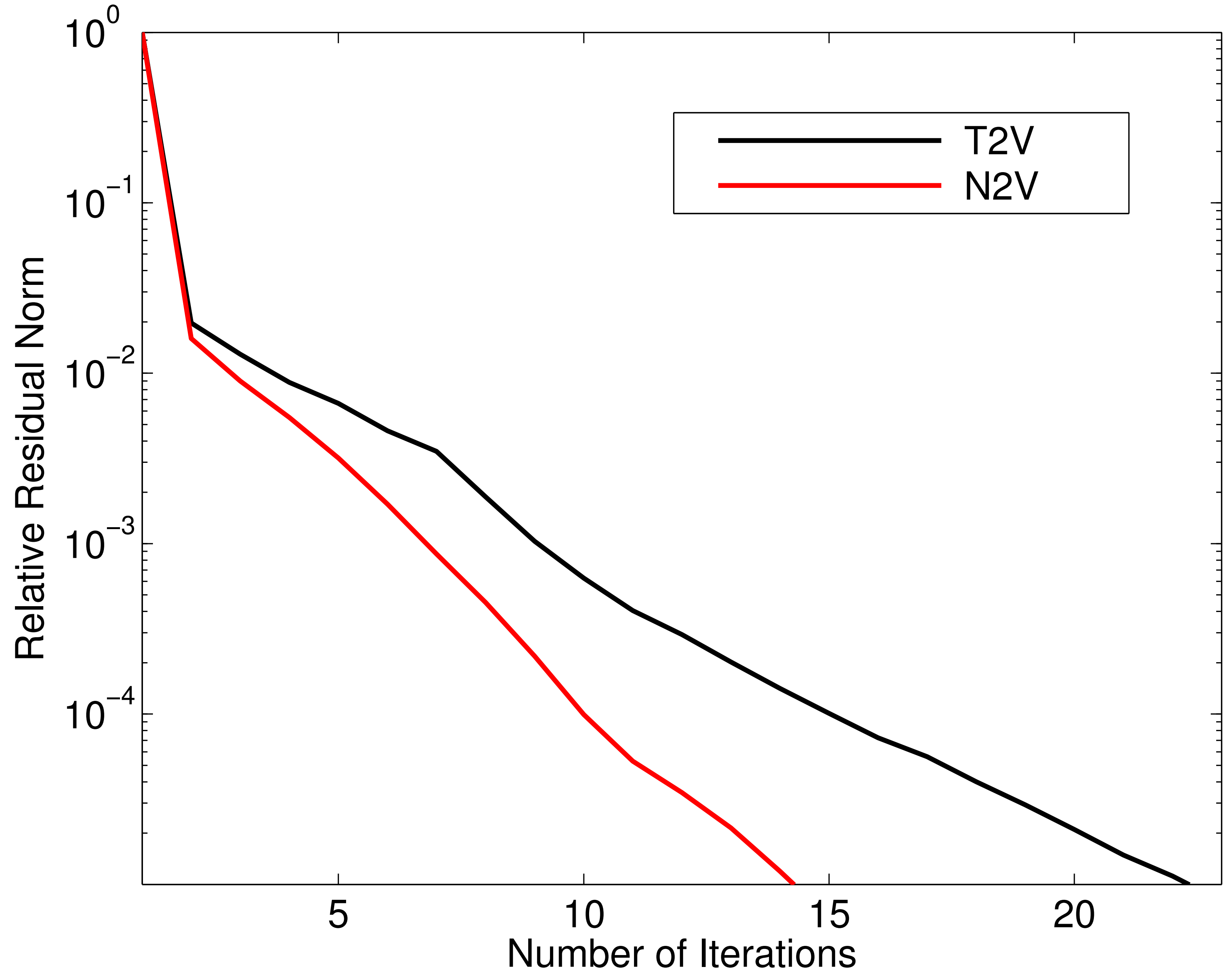


Figure 3 *Second numerical experiment, using 7 points stencil and 10 points per wavelength for SEG/EAGE Overthrust at 8Hz*

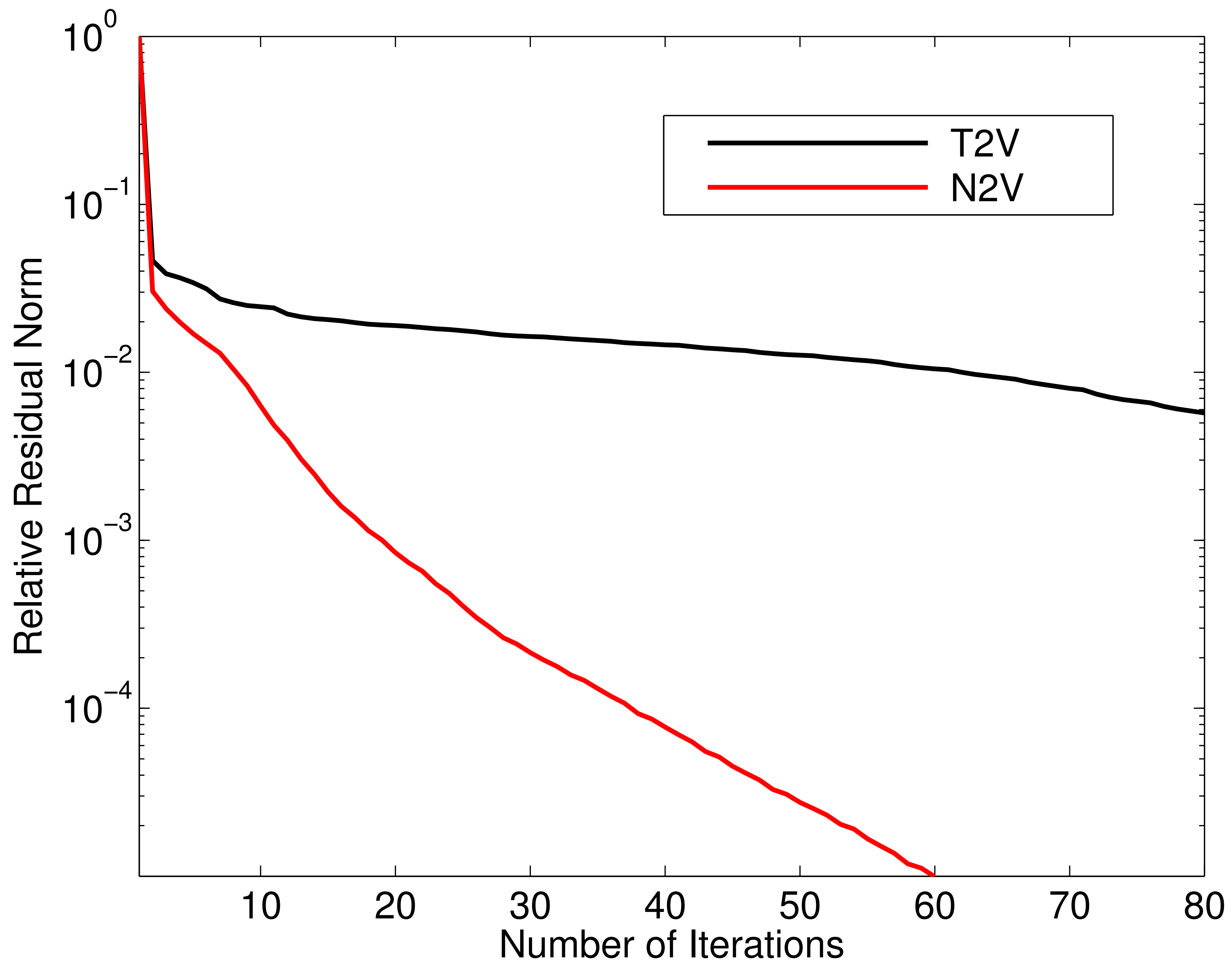


Figure 4 *Second numerical experiment, using 27 points stencil and 6 points per wavelength for SEG/EAGE Overthrust at 8Hz*

Summary

New 27 point stencil - less points per wavelength

New Krylov solvers - less iterations, smooth error decrease for Frugal FWI

New Multigrid preconditioner - less iterations

SLIM

Acknowledgements

Thank you for your attention

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