```
% TITLE: General Inversion of Phase Technique (GIPhT)
%
% OVERVIEW: Synthetic aperture radar (SAR) is an active remote sensing
% technique used for measuring geophysical activity on the Earth?s
 surface.
% It records microwaves transmitted by a sensor (usually aboard a
% satellite) and reflected by features on the Earth?s surface (usually
 on
% land). The reflected signal contains information in the form of
 amplitude
% and phase data, and requires sophisticated post-processing. A
 technique
% known as interferometric SAR (InSAR) measures the difference in
 phase
% between two images of the same area, which can be used to measure
 motion
% and deformation of the ground. In most applications, the
 interferogram
% must be ?unwrapped? before it can be interpreted. The unwrapped
% interferogram may be used to monitor geophysical changes on the
 Earth?s
% surface associated with earthquakes, volcanoes, landslides or
 glaciers,
% or with the withdrawal of oil, gas, water or minerals by extractive
% industries. Unwrapping requires considerable computational power and
% time, and may lead to significant mistakes in the unwrapped
 interferogram
% and thus in its intepretation. UW-Madison researchers have developed
 an
% algorithm for interpreting an interferogram without the need for
% unwrapping. To do so, the invention interprets the interferogram by
% estimating parameters in a quantitative model directly from the
 wrapped
% phase data. Alternative unwrapping algorithms have been developed,
 but
% these can provide inadequate results in areas where the phase data
 are
% imperfect, leading to errors in the unwrapped phase values.
 Likewise,
% these algorithms rarely, if ever, provide uncertainty estimates,
 limiting
% attempts to weight the data in statistical analysis. Implementation
 of
% the invention would reduce the time and resources necessary for
 advanced
% interpretation of InSAR data products, and would provide a more
 accurate
% result that includes an assessment of the uncertainties of the
 parameter
% estimates.
%
```

```
% APPLICATIONS: InSAR for monitoring hazardous natural phenomena,
 e.g.,
% landslides InSAR for monitoring subsidence due to extraction, e.g.,
 oil,
% gas, water KEY
%
% BENEFITS: Validated on real (noisy) data in a peer-reviewed
 publication
% Provides a more direct path to a quantitative interpretation than
% existing methods Provides a realistic assessment of uncertainty,
 unlike
% existing methods
%
% PUBLICATIONS: Feigl, K. L., and C. H. Thurber (2009) A method for
% modelling radar interferograms without phase unwrapping: application
 to
% the M 5 Fawnskin, California earthquake of 1992 December 4 Geophys.
 J.
% Int., 176, 491-504. http://dx.doi.org/10.1111/
j.1365-246X.2008.03881.x
% Interferometric analysis of synthetic aperture radar images (InSAR)
% measures the phase shifts between two images acquired at two
 distinct
% times. These ambiguous 'wrapped' phase values range from -1/2 to
 +1/2
% cycles. The standard approach interprets the phase values in terms
 of the
% change in distance between the ground and the radar instrument by
% resolving the integer ambiguities in a process known as
 'unwrapping'. To
% avoid unwrapping, we have developed, validated and applied a new
 method
% for modelling the wrapped phase data directly. The method defines a
 cost
% function in terms of wrapped phase to measure the misfit between the
% observed and modelled values of phase. By minimizing the cost
 function
% with a simulated annealing algorithm, the method estimates
 parameters in
% a non-linear model. Since the wrapped phase residuals are compatible
 with
% a von Mises distribution, several parametric statistical tests can
 be
% used to evaluate the fit of the model to the data. The method, named
% General Inversion for Phase Technique (GIPhT), can handle noisy,
 wrapped
% phase data. Applying GIPhT to two interferograms in the area of
 Fawnskin,
% California, we estimate a set of model parameters describing a
 magnitude
% 5 aftershock of the 1992 Landers earthquake. The resulting
 simulation
% fits the data well. The phase final residuals have a circular mean
```

```
% deviation less than 0.15 cycles per datum. Sampling the final
 residuals,
% we find the circular standard deviation of a phase measurement to be
% approximately 0.2 cycle, corresponding to 6 mm in range.
%
% LICENSING:
%
% Copyright (c) 2009 Kurt Feigl, Cliff Thurber All rights reserved.

% U.S. Patent No. 7,446,705.
%
% Copyright (c) Kurt Feigl, Cliff Thurber, Lee Powell, Peter Sobol,
 Aaron
% Masters, S. Tabrez Ali, Elena C. Baluyut, University of Wisconsin-
Madison
%
% This program is free software: you can redistribute it and/or modify
 it
% under the terms of the GNU LESSER GENERAL PUBLIC LICENSE as
 published by
% the Free Software Foundation, either version 3 of the License, or
 (at
% your option) any later version.
%
% This program is distributed in the hope that it will be useful, but
% WITHOUT ANY WARRANTY; without even the implied warranty of
% MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
 General
% Public License for more details.
%
% You should have received a copy of the GNU LESSER GENERAL PUBLIC
 LICENSE
% along with this program. If not, see
% http://www.gnu.org/licenses/lgpl.html.

% initialize variables
clear all;
% deal with slashes on Windows boxes
if ispc == 1
    set(0,'DefaultTextInterpreter','none');
end
close all; nf=0;format compact;
echo off all

%splashtext = sprintf('%80s\n',help('gipht.m'));

fprintf(1,'\n\nGeneral Inversion of Phase Technique (GIPhT)\n\n');
versionnum = 2.92;
D=dir(which('gipht'));
versiondat = D.date;
versionstr = sprintf('GIPhT Development version %.1f of %s'...
    ,versionnum,versiondat);

help gipht_splash
```

```
fprintf(1,'\n\n----------------   %s %s ----------
\n',upper(mfilename),versionstr);
fprintf(1,'\n\n----------------   %s begins at %s ----------
\n',upper(mfilename),datestr(now,31));
tstart = tic;


% Modification History below this line
% 2007-2008: Kurt
%     prototyping
% 2009-MAR-28: Lee
%     clean up for demo on Iceland subsidence: 6 pairs
% 2009-MAR-29: Kurt
%     expand to other examples
% 2009-APR-4: Lee
%     add license check and turn off the diary
% 2009-MAY-10: Kurt
%     add option to use coherence
% 2009-JUN-18:
%     Use signed char variables for all phases for speed
%     Introduce pselect = 5 for quadtree
% 2010-JUN: Get gradients to work with pselect == 7
% 2011-JUN:
%     Fix bug in quadtree routines with midpoint of patch
%     Paramterize orbits in terms of incidence angle - correctly
%     Handle missing data
%     Handle correlated parameters
% 2011-JUL
%     Speed up step 5
%     Fix bug with gradients
% 2011-OCT
%     Clean up plots
% 2011-OCT-11
%     for pselect == 7, use test_generalized_paretos to estimate
 critical
%     value of cost
% 2011-NOV-11
%     update for MATLAB R2011b
% 2012-JAN
%     gipht_step3: take max-min for parameter uncertainties
%     add bootstrap to anneal4
%     measure gradients in dimensionless strain
%     Taylor approximation
% 2012-SEP v. 2.5
%     print out derived parameters, too
%     identify bugs when step size in latitude (DL) is positive
%     Add quadtree coordinates to DST
%     Add phaseprefix to gipht.in
%     Fix vector components
% 2013-MAY v. 2.5 (for short course)
%     write_dst.m: write quad dimensions to dst_sample
%     gipht_step1.m: same as above
%     gipht_path.m: handle file separators under Windows and DOS
%     quad_tree: STILL TO DO same as above
```

```
% 2013-MAY v. 2.7
%     improve partial derivatives
%     use comsol
% 2015-JUN v. 2.9.1
%     first version in public repository on GitHub with
%      Lesser GNU Public License
% 2015-JUN v. 2.9.2
%     handle Quadtree data in 14-column format from JPL

% initialize paths
%giphtpath
%path('../src',path);
%path('../extern',path);

%license_check;

clockstr = clock;
runname=sprintf('%04d%02d%02d_%02d%02d%02d'...

 ,clockstr(1),clockstr(2),clockstr(3),clockstr(4),clockstr(5),round(clockstr(6)))
rundir = sprintf('%s',['x_' runname filesep 'x']);
%system(sprintf('mkdir -p x_%s',runname));
unix(sprintf('mkdir -p x_%s',runname));
runname=rundir;
diary(sprintf('%s.log',runname));

if fexist(sprintf('%s.log',runname)) ~= 1
    warning('Cannot open diary file named %s
\n',sprintf('%s.log',runname));
end

% When there is no display, this returns [1 1 1 1] instead of an
 actual screen size. However, this relies on behavior that isn't
 actually specified (by the doc, for instance) to work in any
 particular way, so may be subject to change in the future. If you
 were going to use this many times, it might be wise to wrap it in
 a function (e.g. create an "isdisplay.m" function file), so you can
 easily change the implementation in the future, if needed. (This
 method worked as of MATLAB R2008a.)
ss4 = get(0, 'ScreenSize');
if ss4 == [1 1 1 1 ]
%warning('off','all');
end

% % Make a figure with splash message
% figure;set(gca,'Visible','Off');axis([0 30 0 20]); hold on;
% h=text(0.05,10,char(splashtext));
% set(h,'FontName','Helvetica','Fontsize',10,'FontWeight','bold');
% printpdf(sprintf('%s.pdf',runname));

% count the errors
nerrors = 0;

% Now run the following steps:
```

```
gipht_step1; % read in phase files, select pixels
gipht_step2; % set bounds on parameters, run simulated annealing
gipht_step3; % determine statistical uncertainties on parameter
 estimates
gipht_step4; % make images for quad tree
gipht_step5; % make images for entire sub-region

save_run;
telapsed = toc(tstart);
fprintf(1,'\n\n----------------   %s ended normally at %s ----------
\n',upper(mfilename),datestr(now,31));
fprintf(1,    '----------------   Elapsed time: %.0f seconds
\n',telapsed);

diary off
```

```
General Inversion of Phase Technique (GIPhT)

  Copyright (c) Kurt Feigl, Cliff Thurber  All rights reserved.
  U.S. Patent No. 7,446,705.

  This program is free software: you can redistribute it and/or modify
 it
  under the terms of the GNU LESSER GENERAL PUBLIC LICENSE as
 published by
  the Free Software Foundation, either version 3 of the License, or
 (at
  your option) any later version.

  This program is distributed in the hope that it will be useful, but
  WITHOUT ANY WARRANTY; without even the implied warranty of
  MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU
 General
  Public License for more details.

  You should have received a copy of the GNU LESSER GENERAL PUBLIC
 LICENSE
  along with this program. If not, see http://www.gnu.org/licenses/
lgpl.html .

  Source code: Copyright (c) Kurt Feigl, Cliff Thurber, Lee Powell,
 Peter
  Sobol, Aaron Masters Elena Baluyut, S. Tabrez Ali
  University of Wisconsin-Madison'



----------------   GIPHT GIPhT Development version 2.9 of 21-Jul-2015
 18:29:46 ----------


----------------   GIPHT begins at 2015-07-21 19:50:31 ----------
```

```
runname =
20150721_195031


----------------   GIPHT_STEP1 begins at 2015-07-21 19:50:31
 ----------
read_input_controls begin reading input control file named gipht.in...
    1 xcenter  39.35466       % X coordinate of center of sampled
 region
    2 ycenter  38.36103        % Y coordinate of center of sampled
 region
    3 halfwidth  130         % half the east-west width of the sampled
 region in pixels
    4 demdescfile  dem_descriptor.dat
    5 pselect  5        % select pixels of phase using quadtree
    6 pixinpatch  16        % mininum number of valid (nonzero) pixels
 in a patch
    7 ithresh      32        % minimum misfit (circular mean
 deviation) to mean ( 1 DN is 1 / 256 pixel)
    8 maxcmd      16        % minimum misfit (circular mean deviation)
 to ramp ( 1 DN is 1 / 256 pixel)
    9 mpercy  0.0284 % meters for ENVISAT, ERS-1, and ERS-2
   10 unitv_east   0.382192  % Eastward component
   11 unitv_north  -0.081237  % Northward component
   12 unitv_up   0.920500  % Upward component (must be positive)
   13 txtinname  demoZ4.gin   % One Okada with with new format for
 Beauducel parameterization FAILS?
   14 objfun  funcostrarc         % mininum angle,  assumes zero mean,
 using arc function in radians
   15 fitfun  funfit28
   16 surrogate  1       % use fast approximate version of fitting
 function (1st order Taylor series)
   17 nprocessors  0     % number of processors to use in Distributed
 Computing Toolbox
   18 anneal  4  %     4 to use approximate fitting function with
 surrogate
   19 figopt  010 % simple for demo
   20 printfun  printnull % do not write figures to files (fast)
   21 verbose  2 % debug and tell us everything
              xcenter = 39.354660
              ycenter = 38.361030
            halfwidth = 130.000000
              pselect = 5.000000
           unitv_east = 0.382192
          unitv_north = -0.081237
             unitv_up = 0.920500
              ithresh = 32.000000
               anneal = 4.000000
           pixinpatch = 16.000000
          nprocessors = 0.000000
               mpercy = 0.028400
               maxcmd = 16.000000
               figopt = 00000010
            surrogate = 1.000000
```

```
             verbose = 2.000000
              objfun = funcostrarc
              fitfun = funfit28
           txtinname = demoZ4.gin
         demdescfile = dem_descriptor.dat
            printfun = printnull
WARNING: No orbit file named in gipht.in. Assuming constant look
 vector.
demoZ4.gin
dem_descriptor.dat
file_names.dat
cmds =
    'funfit28'    'printnull'    'funcostrarc'
Using "exist" command to search for function named funfit28
Found function named funfit28 2
Using "exist" command to search for function named printnull
Found function named printnull 2
Using "exist" command to search for function named funcostrarc
Found function named funcostrarc 2
read_input_controls completed reading input controls.
Scale factor for phase in DN per cycle:
DNPC =
   6.283185307179586
Name of list of phase files
read_file_names begins ...
Read    1 pairs of phase files
Number of interferogram files (pairs) to adjust
np =
     1
Number of distinct epochs overall
me =
     2
Number of species overall
mfam =
     1
Species A:     1     2
Species A Member  1 Pair   1 M   1001 S   1002
                                  psp_16851_28374_ort.pha
Species A Member  2 Pair   1 M   1001 S   1002
                                  psp_16851_28374_ort.pha
adjustbp begins ...
Length of data vector, including constraints
md =
     1     2
Dimensons of design matrix, including constraints
nmdd2 =
     2     2
Rank defiency, including constraints
rd =
     0
Begin least squares adjustment...
index orbnum date     species yr Dopp/PRF
    1    1001 PAIR001-MAST A  2005.3836     0.0000
    2    1002 PAIR001-SLAV A  2007.5890  1000.0000
```

```
plotbp begins at 2015-07-21 19:50:31
titl1 =
Selected pairs
Pair trees Member0 Member1 orbn0 orbn1 year0 year1 year Bperp (m)
plotbp ended at 2015-07-21 19:50:32
read_dem_descriptor begins ...
DEM Descriptor specifies entire file.
Reached end of DEM descriptor file
number of columns in each interferogram
ncols =
        1878
number of lines in each interferogram
nrows =
        1419
Maximum number of pixels to be selected for inversion = 2664882
Location                  X            Y
DEM pixel 1             39           39
DEM extract 1           39           39
DEM extract N           40           38
Center                  39           38
icenter = 598 jcenter = 1004
Subregion contains NRSUB = 201 rows and NCSUB = 261 columns
dx =
  71.814566380868200
dy =
 -92.856065906584263
xcenter1 =
     5.308684427464893e+05
ycenter1 =
     4.246095451900252e+06
utmzone0 =
37 S
xcenter2 =
     5.302815020291234e+05
ycenter2 =
     4.245752532012055e+06
xcenter3 =
     5.301671729508673e+05
ycenter3 =
     4.245916330334709e+06
Warning: WARNING: problem with UTM coordinates for center point.
xcenter1 =
     530868.44
xcenter2 =
     530281.50
diffx =
       -586.94
ycenter2 =
    4245752.53
ycenter1 =
    4246095.45
diffy =
       -342.92
xcenter =
```

```
     530281.50
ycenter =
    4245752.53

Error using read_i2 (line 21)
Cannot open file
             sivrice_dem.i2

Error in gipht_step1 (line 641)
i2dem = read_i2(fi2,nc);
Error in gipht (line 206)
gipht_step1; % read in phase files, select pixels
```

Published with MATLAB® R2015a