```
Result('legacy','grey title="Legacy"')
Result('hires-agc','hires',
       'agc rect1=2000 rect2=5 | grey title="High-resolution"')

# frequency content
Flow('legacy-spec','legacy','spectra all=y')
Result('nspectra-orig','high-spec legacy-spec',
     '''cat axis=2 ${SOURCES[1]} | scale axis=1 | window max1=180 |
        graph title="Normalized Spectra" label2="Amplitude" unit2=""''')

# Balance local frequency
flol=40
corrections = 5
Flow('legacyfilt','legacy','bandpass flo=%d '%(flol))
radius('hires','legacyfilt', corrections, [0.13,0.2,0.3,0.5,0.5],
       bias=0, clip=90, rect1=80, rect2=16, maxval=90 )

End()
```

Listing 2: chapter-locfreq/merge/radius.py

```
from rsf.proj import *

def radius(high, low,               # initial high and low frequency images
           niter,                   # number of corrections
           c,                       # 'step length' for radius corrections. Can
                                    #       be type int or float for constant c
                                    #       or type array for changing c.
           bias=-15, clip=30,       # bias and clip for display
           rect1=40, rect2=80,      # radius for local frequency calculation
           maxrad=1000,             # maximum allowed radius
           theor=True,              # use theoretical smoothing radius
           scale=9,                 # scale for theoretical smoothing radius
           initial=10,              # initial value for contant smoothing radius
           minval=0, maxval=25,     # min and max local frequency for display
           titlehigh="Hires",
           titlelow="Legacy"):

    if type(c) is float or type(c) is int:
        c = [c]*niter

    # plot image
    def seisplot(name):
        return 'grey title="%s"'%name

    # local frequency
    locfreq = '''iphase order=10 rect1=%d rect2=%d hertz=y complex=y |
                 put label="Frequency" unit=Hz'''%(rect1,rect2)

    def locfreqplot(name):
        return 'grey mean=y color=j scalebar=y title="%s" '%name

    # difference in local frequencies
    freqdif = 'add scale=-1,1 ${SOURCES[1]} | put label=Frequency'

    def freqdifplot(num):
        return '''grey allpos=y color=j scalebar=y mean=y
                  title="Difference in Local Frequencies %s"
                  clip=%d bias=%d minval=%d
                  maxval=%d''' %(num,clip,bias,minval,maxval)

```

```
    # plot spectral content
42  specplot = '''cat axis=2 ${SOURCES[1]} |
                scale axis=1 | window max1=180 |
44              graph title="Normalized Spectra" label2="Amplitude" unit2=""'''

46  # plot smothing radius
    def rectplot(name):
48      return '''grey color=j mean=y title="%s" scalebar=y barlabel=Radius
                barunit=samples'''%name
50
    # smooth with radius
52  smooth = 'nsmooth1 rect=${SOURCES[1]}'

54  ##############################################################################

56  # plot images
    Result(high, seisplot(titlehigh))
58  Result(low, seisplot(titlelow))

60  # initial local frequency
    Flow('high-freq',high,locfreq)
62  Result('high-freq',locfreqplot('%s Local Frequency'%titlehigh))

64  Flow('low-freq',low,locfreq)
    Result('low-freq',locfreqplot('%s Local Frequency'%titlelow))
66
    # initial difference in local frequency
68  Flow('freqdif','low-freq high-freq',freqdif)
    Result('freqdif',freqdifplot(''))
70
    # initial smoothing radius
72  if (theor):
        from math import pi
74      Flow('rect0','low-freq high-freq','''math f1=${SOURCES[1]}
        output="sqrt(%g*(1/(input*input)-1/(f1*f1)))/%g"'''%(scale,2*pi*0.001))
76  else:
        Flow('rect0','low-freq','math output=%f'%initial)
78
    Result('rect0',rectplot("Smoothing Radius 0"))
80
    # smoothing using intial smoothing radius guess
82  Flow('high-smooth0','%s rect0' % high,smooth)
    Result('high-smooth0', seisplot("%s Smooth 0"%titlehigh))
84
    # frequency spectra
86  Flow('high-spec',high,'spectra all=y')
    Flow('low-spec',low,'spectra all=y')
88  Flow('high-smooth-spec0','high-smooth0','spectra all=y')
    Result('nspectra','high-spec low-spec',specplot)
90  Result('high-smooth-spec0','high-smooth-spec0 low-spec',specplot)

92  Flow('high-smooth-freq0','high-smooth0',locfreq)
    Result('high-smooth-freq0',
94          locfreqplot("%s Local Frequency Smoothed %d" %(titlehigh,0)))

96  Flow('freqdif-filt0','low-freq high-smooth-freq0',freqdif)
    Result('freqdif-filt0',freqdifplot('0'))
98
    prog=Program('radius.c')
100 for i in range(1, niter+1):
        j = i-1
```

```
102
        # update smoothing radius
104     Flow('rect%d'%i,'rect%d freqdif-filt%d %s'%(j,j,prog[0]),
            './${SOURCES[2]} freq=${SOURCES[1]} c=%f'%c[j])
106     Result('rect%d'%i,rectplot("Smoothing Radius %d")%i)

108     # smooth image with radius
        Flow('high-smooth%d'%i,'%s rect%d'%(high,i),smooth)
110     Result('high-smooth%d'%i, seisplot('%s Smooth %d'%(titlehigh,i)))

112     # smoothed spectra
        Flow('high-smooth-spec%d'%i,'high-smooth%d'%i,'spectra all=y')
114     Result('high-smooth-spec%d'%i,'high-smooth-spec%d low-spec'%i,specplot)

116     # smoothed local frequency
        Flow('high-smooth-freq%d'%i,'high-smooth%d'%i,locfreq)
118     Result('high-smooth-freq%d'%i,
               locfreqplot('%s Local Frequency Smoothed %d'%(titlehigh,i)))
120
        # frequency residual
122     Flow('freqdif-filt%d'%i,'low-freq high-smooth-freq%d'%i,freqdif)
        Result('freqdif-filt%d'%i,freqdifplot(str(i)))
```

Listing 3: chapter-locfreq/merge/radius.c

```
/* smoothing radius (min = 1) */
2 #include <rsf.h>
#include <math.h>
4
int main (int argc, char* argv[])
6 {
    int n1, n1f, n2, n2f, i, n12, n12f;
8   float *rect, *fr, maxrad, c, *rad;
    sf_file in, out, freq;
10
    sf_init (argc,argv);
12
    in = sf_input("in");
14  freq = sf_input("freq");
    out = sf_output("out");
16
    if (!sf_histint(in,"n1",&n1)) sf_error("No n1= in input.");
18  if (!sf_histint(freq,"n1",&n1f)) sf_error("No n1= in frequency difference.");

20  n2 = sf_leftsize(in,1);
    n2f = sf_leftsize(freq,1);
22
    n12 = n1*n2;
24  n12f = n1f*n2f;

26  if (n1 != n1f) sf_error("Need matching n1");
    if (n2 != n2f) sf_error("Need matching n2");
28
    if (!sf_getfloat("c",&c)) c=1.;
30  if (!sf_getfloat("maxrad",&maxrad)) maxrad=1000.;

32  rect = sf_floatalloc(n12);
    sf_floatread(rect,n12,in);
34
    fr = sf_floatalloc(n12f);
36  sf_floatread(fr,n12,freq);
```

```
    rad = sf_floatalloc(n12);

    for (i=0; i < n12; i++) {

        /* update radius */
      rad[i] = rect[i]+c*fr[i];

        /* set constraint conditions: [1, maxrad] */
        if (rad[i] > maxrad)
                rad[i] = maxrad;
        if (rad[i] < 1.0)
                rad[i] = 1.0;
    }

    sf_floatwrite(rad,n12,out);
    exit(0);
}
```

Bibliography

Al-Inaizi, S., R. Bridle, and N. Nakhla, 2004, Comparison of pre and post-stack supermerge of ten 3D blocks: Presented at the 74th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Aoki, N., and G. T. Schuster, 2009, Fast least-squares migration with a deblurring filter: GEOPHYSICS, **74**, WCA83–WCA93.

Bader, S., X. Wu, and S. Fomel, 2018, Missing log data interpolation and semiautomatic seismic well ties using data matching techniques: Interpretation. (Submitted).

Carter, D., and S. Pambayuning, 2009, Extended bandwidth by a frequency domain merge of two 3D seismic volumes: The Leading Edge, **28**, 386–386.

Casasanta, L., F. Perrone, G. Roberts, A. Ratcliffe, K. Purcell, A. Jafargandomi, and G. Poole, 2017, Applications of single-iteration Kirchhoff least-squares migration: Presented at the 87th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Claerbout, J. F., 1992, Earth Soundings Analysis: Processing Versus Inversion: Blackwell Scientific Publications.

Dai, W., and G. T. Schuster, 2013, Plane-wave least-squares reverse-time migration: GEOPHYSICS, **78**, S165–S177.

Dong, S., J. Cai, M. Guo, S. Suh, Z. Zhang, B. Wang, and Z. Li, 2012, Least-squares reverse time migration: towards true amplitude imaging and improving the resolution: Presented at the 82nd Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Dutta, G., Y. Huang, W. Dai, X. Wang, and G. T. Schuster, 2014, Making the most out of the least (squares migration): 84th Annual International Meeting, SEG, Expanded Abstracts, 4405–4410.

Fomel, S., 2007a, Local seismic attributes: GEOPHYSICS, **72**, A29–A33.

———, 2007b, Shaping regularization in geophysical-estimation problems: GEOPHYSICS, **72**, R29–R36.

Fomel, S., M. Backus, K. Fouad, B. Hardage, and G. Winters, 2005, A multistep approach to multicomponent seismic image registration with application to a West Texas carbonate reservoir study: 75th Ann. Internat. Mtg, Soc. of Expl. Geophys., 1018–1021.

Fomel, S., and M. M. Backus, 2003a, Multicomponent seismic data registration by least squares: Presented at the 73rd Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

———, 2003b, Multicomponent seismic data registration by least squares: 73rd Annual International Meeting, Soc. of Expl. Geophys., 701–784.

Fomel, S., and L. Jin, 2009, Time-lapse image registration using the local similarity attribute: GEOPHYSICS, **74**, A7–A11.

Fomel, S., P. Sava, I. Vlad, Y. Liu, and V. Bashkardin, 2013, Madagascar: open-source software project for multidimensional data analysis and reproducible computational experiments: Journal of Open Research Software, **1**, e8.

Gholamy, A., and V. Kreinovich, 2014, Why ricker wavelets are successful in processing seismic data: Towards a theoretical explanation: Presented at the 2014 IEEE Symposium on Computational Intelligence for Engineering Solutions (CIES), IEEE.

Greer, S., and S. Fomel, 2017a, Balancing local frequency content in seismic data

using non-stationary smoothing: , Society of Exploration Geophysicists, 4278 – 4282.

———, 2017b, Matching and merging high-resolution and legacy seismic images: , Society of Exploration Geophysicists, 5933 – 5937.

———, 2018, Matching and merging high-resolution and legacy seismic images: GEOPHYSICS, **83**, V115–V122.

Greer, S., Z. Xue, and S. Fomel, 2018, Improving migration resolution by approximating the least-squares hessian using non-stationary amplitude and frequency matching: Presented at the 88th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists. (Submitted).

Guitton, A., 2004, Amplitude and kinematic corrections of migrated images for nonunitary imaging operators: GEOPHYSICS, **69**, 1017–1024.

———, 2017, Fast 3D least-squares RTM by preconditioning with nonstationary matching filters: Presented at the 87th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Hale, D., 2013, Dynamic warping of seismic images: GEOPHYSICS, **78**, S105–S115.

Hardage, B. A., M. V. DeAngelo, P. E. Murray, and D. Sava, 2011, Multicomponent seismic technology: Society of Exploration Geophysicists.

Herrera, R. H., S. Fomel, and M. van der Baan, 2014, Automatic approaches for seismic to well tying: Interpretation, **2**, SD9–SD17.

Herrera, R. H., and M. van der Baan, 2012, Guided seismic-to-well tying based on dynamic time warping: 82nd Annual International Meeting, Society of Exploration Geophysicists, 1–5.

Hestenes, M. R., and E. Stiefel, 1952, Methods of Conjugate Gradients for Solving

Linear Systems: Journal of Research of the National Bureau of Standards, **49**, 409–436.

Hou, J., and W. Symes, 2016, Accelerating least squares migration with weighted conjugate gradient iteration: Presented at the 78th EAGE Conference and Exhibition 2016, EAGE Publications BV.

Hou, J., and W. W. Symes, 2015, An approximate inverse to the extended born modeling operator: GEOPHYSICS, **80**, R331–R349.

Hu, J., and G. T. Schuster, 1998, Migration deconvolution: Presented at the Mathematical Methods in Geophysical Imaging V, SPIE.

Hu, J., G. T. Schuster, and P. A. Valasek, 2001, Poststack migration deconvolution: GEOPHYSICS, **66**, 939–952.

Kuehl, H., and M. D. Sacchi, 2003, Least-squares wave-equation migration for AVP/AVA inversion: GEOPHYSICS, **68**, 262–273.

Liu, Y., and S. Fomel, 2012, Seismic data analysis using local time-frequency decomposition: Geophysical Prospecting, **61**, 516–525.

Lumley, D., D. C. Adams, M. Meadows, S. Cole, and R. Wright, 2003, 4D seismic data processing issues and examples: 73rd Annual International Meeting, Society of Exploration Geophysicists, 1394–1397.

Meckel, T., N. L. Bangs, and T. Hess, 2017, 3D multichannel seismic field data from the San Luis Pass region off Galveston, Texas, acquired by the R/V Brooks-McCall in 2013 (BM1310).

Meckel, T. A., and F. J. Mulcahy, 2016, Use of novel high-resolution 3D marine seismic technology to evaluate Quaternary fluvial valley development and geologic controls on shallow gas distribution, inner shelf, Gulf of Mexico: Interpretation, **4**, SC35–SC49.

Mohan, T. R. M., C. B. Yadava, S. Kumar, K. K. Mishra, and K. Niyogi, 2007, Prestack merging of land 3D vintages — a case history from Kavery Basin, India: Presented at the 77th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Müller, M., 2007, Dynamic time warping, *in* Information Retrieval for Music and Motion: Springer Berlin Heidelberg, 69–84.

Paffenholz, J., B. McLain, J. Zaske, and P. Keliher, 2002, Subsalt multiple attenuation and imaging: Observations from the Sigsbee2B synthetic dataset: 72nd Annual International Meeting, SEG, Expanded Abstracts, 2122–2125.

Petersen, C. J., S. Buenz, S. Hustoft, J. Mienert, and D. Klaeschen, 2010, High-resolution P-Cable 3D seismic imaging of gas chimney structures in gas hydrated sediments of an Arctic sediment drift: Marine and Petroleum Geology, **27**, 19811994.

Phillips, M., and S. Fomel, 2016, Seismic time-lapse image registration using amplitude-adjusted plane-wave destruction: 86th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists, 5473–5478.

Rickett, J. E., 2003, Illumination-based normalization for wave-equation depth migration: GEOPHYSICS, **68**, 1371–1379.

Ross, C. P., and M. S. Altan, 1997, Time-lapse seismic monitoring: Some shortcomings in nonuniform processing: The Leading Edge, **16**, 931–937.

Sacchi, M. D., J. Wang, and H. Kuehl, 2007, Estimation of the diagonal of the migration blurring kernel through a stochastic approximation: Presented at the 77th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Schuster, G. T., 2017, Seismic inversion: Society of Exploration Geophysicists.

Tsinaslanidis, P., A. Alexandridis, A. Zapranis, and E. Livanis, 2014, Dynamic time warping as a similarity measure: Applications in finance: Presented at the Hellenic Finance and Accounting Association.

Ursenbach, C., P. Cary, and M. Perz, 2013, Limits on resolution enhancement for PS data mapped to PP time: The Leading Edge, **32**, 64–71.

White, R. E., 1991, Properties of instantaneous seismic attributes: The Leading Edge, **10**, 26–32.

Xue, Z., Y. Chen, S. Fomel, and J. Sun, 2016, Seismic imaging of incomplete data and simultaneous-source data using least-squares reverse-time migration with shaping regularization: GEOPHYSICS, **81**, no. 1, S11–S20.

Yu, J., J. Hu, G. T. Schuster, and R. Estill, 2006, Prestack migration deconvolution: GEOPHYSICS, **71**, S53–S62.

Zhou, J., J. Sun, and X. Ma, 2014, Application of Gabor transform to amplitude spectrum matching for merging seismic surveys: Presented at the 84th Annual International Meeting, SEG, Expanded Abstracts, Society of Exploration Geophysicists.

Vita

Sarah graduated with high honors from Cinco Ranch High School in Katy, Texas in 2014 and came to The University of Texas at Austin to pursue her undergraduate studies. She is a candidate for a Bachelor of Science degree in Geophysics from the Jackson School of Geosciences and a Bachelor of Science degree in Mathematics from the College of Natural Sciences. After graduation, she plans on pursuing a PhD in Mathematics and Computational Science at the Massachusetts Institute of Technology.

Permanent address: 2175 Stonecrest Drive, Eugene, OR, 97401, USA

This thesis was typeset with LaTeX[†] by the author.

[†]LaTeX is a document preparation system developed by Leslie Lamport as a special version of Donald Knuth's TeX Program.