Waves and Imaging Class notes - 18.325

Laurent Demanet

Draft April 7, 2015

## **Preface**

In the margins of this text we use

- the symbol (!) to draw attention when a physical assumption or simplification is made; and
- the symbol (\$) to draw attention when a mathematical fact is stated without proof.

Thanks are extended to the following people for discussions, suggestions, and contributions to early drafts: William Symes, Thibaut Lienart, Nicholas Maxwell, Pierre-David Letourneau, Russell Hewett, and Vincent Jugnon.

These notes are accompanied by computer exercises in Python, that show how to code the adjoint-state method in 1D, in a step-by-step fashion, from scratch. They are provided by Russell Hewett, as part of our software platform, the Python Seismic Imaging Toolbox (PySIT), available at http://pysit.org.

## Contents

1	Wa	Wave equations				
	1.1	Physical models				
		1.1.1 Acoustic waves				
		1.1.2 Elastic waves				
		1.1.3 Electromagnetic waves				
	1.2	Special solutions				
		1.2.1 Plane waves, dispersion relations 19				
		1.2.2 Traveling waves, characteristic equations				
		1.2.3 Spherical waves, Green's functions				
		1.2.4 The Helmholtz equation				
		1.2.5 Reflected waves				
	1.3	Exercises				
2	Geo	ometrical optics 43				
	2.1	Traveltimes and Green's functions				
	2.2	Rays				
	2.3	Amplitudes				
	2.4	Caustics				
	2.5	Exercises				
3	Scattering series 55					
	3.1	Perturbations and Born series				
	3.2	Convergence of the Born series (math)				
	3.3	Convergence of the Born series (physics) 63				
	3.4	A first look at optimization				
	3.5	Exercises				

6 CONTENTS

4	Adjoint-state methods	73		
	4.1 The imaging condition	74		
	4.2 The imaging condition in the frequency domain	78		
	4.3 The general adjoint-state method	79		
	4.4 The adjoint state as a Lagrange multiplier	84		
	4.5 Exercises	85		
5	Synthetic-aperture radar			
	5.1 Assumptions and vocabulary	87		
	5.2 Forward model	89		
	5.3 Filtered backprojection	92		
	5.4 Resolution	97		
	5.5 Exercises	97		
6	Computerized tomography	99		
	6.1 Assumptions and vocabulary	99		
	6.2 The Radon transform and its inverse			
	6.3 Exercises	101		
7	Seismic imaging 1			
	7.1 Assumptions and vocabulary	103		
	7.2 Kirchhoff modeling and migration			
	7.3 Depth extrapolation	106		
	7.4 Extended modeling			
	7.5 Exercises	106		
8	Microlocal analysis of imaging			
	8.1 Preservation of the wavefront set	107		
	8.2 Characterization of the wavefront set	113		
	8.3 Pseudodifferential theory			
	8.4 Exercises			
9	Optimization			
	9.1 Regularization and sparsity	<b>121</b> 121		
	9.2 Dimensionality reduction techniques			
$\mathbf{A}$	Calculus of variations, functional derivatives	123		
В	Finite difference methods for wave equations 12			

CONTENTS	7
C Stationary phase	129

8 CONTENTS

18.325 Topics in Applied Mathematics: Waves and Imaging Fall 2015

For information about citing these materials or our Terms of Use, visit: https://ocw.mit.edu/terms.