Table of contents

N	Nomenclature				
1	Intr	oducti	on: The Importance of Knowing What We Don't Know	1	
	1.1	Deep l	earning	2	
	1.2 Model uncertainty				
	1.3	Model	uncertainty and AI safety	9	
		1.3.1	Physician diagnosing a patient	9	
		1.3.2	Autonomous vehicles	9	
		1.3.3	Critical systems and high frequency trading	10	
	1.4	Applie	eations of model uncertainty	11	
		1.4.1	Active learning	11	
		1.4.2	Efficient exploration in deep reinforcement learning	12	
	1.5	Model	uncertainty in deep learning	13	
	1.6	Thesis	structure	16	
2	The	Langi	uage of Uncertainty	17	
	2.1	Bayesian modelling			
2		2.1.1	Variational inference	19	
	2.2	Bayesi	an neural networks	20	
		2.2.1	Brief history	20	
		2.2.2	Modern approximate inference	23	
		2.2.3	Challenges	27	
3	Bay	esian l	Deep Learning	29	
	3.1	Advan	ced techniques in variational inference	30	
		3.1.1	Monte Carlo estimators in variational inference	30	
		3.1.2	Variance analysis of Monte Carlo estimators in variational inference	34	
	3.2	Practi	cal inference in Bayesian neural networks	37	

Table of contents

		3.2.1	Stochastic regularisation techniques	. 39				
		3.2.2	Stochastic regularisation techniques as approximate inference	. 41				
		3.2.3	KL condition	. 44				
	3.3	Model	uncertainty in Bayesian neural networks	. 47				
		3.3.1	Uncertainty in classification	. 51				
		3.3.2	Difficulties with the approach	. 54				
	3.4	Appro	eximate inference in complex models	. 56				
		3.4.1	Bayesian convolutional neural networks	. 56				
		3.4.2	Bayesian recurrent neural networks	. 58				
4	Uno	Uncertainty Quality						
	4.1	Effects	s of model structure on uncertainty	. 62				
	4.2	Effects	s of approximate posterior on uncertainty	. 63				
		4.2.1	Regression	. 66				
		4.2.2	Classification	. 71				
	4.3	3 Quantitative comparison						
	4.4	4 Bayesian convolutional neural networks						
		4.4.1	Model over-fitting	. 80				
		4.4.2	MC dropout in standard convolutional neural networks	. 80				
		4.4.3	MC estimate convergence	. 82				
	4.5	5 Recurrent neural networks						
	4.6	Heteroscedastic uncertainty						
5	App	Applications 8						
	5.1	Recen	t literature	. 88				
		5.1.1	Language applications	. 89				
		5.1.2	Medical diagnostics and bioinformatics	. 89				
		5.1.3	Computer vision and autonomous driving	. 90				
	5.2	Active	e learning with image data	. 91				
	5.3	Exploration in deep reinforcement learning						
	5.4	4 Data efficiency in deep reinforcement learning						
		5.4.1	PILCO	. 98				
		5.4.2	Deep PILCO	. 100				
		5.4.3	Experiment	. 102				
6	Dee	Deep Insights						
	6.1	Practi	cal considerations for getting good uncertainty estimates	. 105				

Table of contents xi

	6.2 What determines what our uncertainty looks like?						
	6.3	Analy	tical analysis in Bayesian linear regression	. 107			
	6.4 ELBO correlation with test log likelihood						
	6.5	<u> </u>					
	6.6	Dropout as a proxy posterior in spike and slab prior models					
		6.6.1	Historical context	. 121			
		6.6.2	Spike and slab prior models	. 122			
		6.6.3	Related work	. 123			
		6.6.4	Approximate inference with free-form variational distributions .	. 123			
		6.6.5	Proxy optimal approximating distribution	. 124			
		6.6.6	Spike and slab and dropout	. 126			
	6.7	Episte	emic, Aleatoric, and Predictive uncertainties	. 127			
7	Fut	ure Re	esearch	133			
References							
Appendix A KL condition 14							
$\mathbf{A}_{]}$	Appendix B Figures						
\mathbf{A}	Appendix C Spike and slab prior KL 1						