Bayesian Nonparametrics:
Gaussian Process
Reminders

• Cloud Credits (AWS or GCP)
  – first request deadline: Thu at 11:59pm

• Quiz 3
  – Mon, May 3 during lecture slot
  – Topics: Lectures 16 - 23
QUIZ 2 LOGISTICS
Quiz 2

• **Time / Location**
  – **Time:** In-Class Quiz  
    **Wed, Apr. 14 during lecture time**
  – **Location:** The same Zoom meeting as lecture/recitation. Please arrive online early.
  – Please watch Piazza carefully for announcements.

• **Logistics**
  – Covered material: Lecture 9 – Lecture 15  
    (and unavoidably some material from Lectures 1 – 8)
  – **Format of questions:**
    • Multiple choice
    • True / False (with justification)
    • Derivations
    • Short answers
    • Interpreting figures
    • Implementing algorithms on paper
    • Drawing
  – No electronic devices
  – You are allowed to **bring** one 8½ x 11 sheet of notes (front and back)
Quiz 2

• **Advice (for before the exam)**
  – Try out the Gradescope quiz-style interface in the “Fake Quiz” now available

• **Advice (for during the exam)**
  – Solve the easy problems first (e.g. multiple choice before derivations)
    • if a problem seems extremely complicated you’re likely missing something
  – Don’t leave any answer blank!
  – If you make an assumption, write it down
  – If you look at a question and don’t know the answer:
    • we probably haven’t told you the answer
    • but we’ve told you enough to work it out
    • imagine arguing for some answer and see if you like it
Topics for Quiz 1

• Graphical Model Representation
  – Directed GMs vs. Undirected GMs vs. Factor Graphs
  – Bayesian Networks vs. Markov Random Fields vs. Conditional Random Fields

• Graphical Model Learning
  – Fully observed Bayesian Network learning
  – Fully observed MRF learning
  – Fully observed CRF learning
  – Parameterization of a GM
  – Neural potential functions

• Exact Inference
  – Three inference problems: (1) marginals, (2) partition function, (3) most probably assignment
  – Variable Elimination
  – Belief Propagation (sum-product and max-product)
Topics for Quiz 2

• Learning for Structure Prediction
  – Structured Perceptron
  – Structured SVM
  – Neural network potentials

• (Approximate) MAP Inference
  – MAP Inference via MILP
  – MAP Inference via LP relaxation

• Approximate Inference by Sampling
  – Monte Carlo Methods
  – Gibbs Sampling
  – Metropolis-Hastings
  – Markov Chains and MCMC

• Parameter Estimation
  – Bayesian inference
  – Topic Modeling
Topics for Quiz 3

• Approximate Inference by Optimization
  – Variational Inference
  – Mean Field Variational Inference
  – Coordinate Ascent V.I. (CAVI)
  – Variational EM
  – Variational Bayes

• Deep Generative Models
  – Variational Autoencoders
  – Sigmoid Belief Networks, Restricted Boltzmann Machines, Deep Belief Nets, Deep Boltzmann Machines

• Bayesian Nonparametrics
  – Dirichlet Process
  – DP Mixture Model
  – Indian Buffet Process
GAUSSIAN PROCESS
Motivation: Gaussian Process

Density Estimation

- Given data, estimate a probability density function that best explains it
- A nonparametric prior can be placed over an infinite set of distributions

Prior:

Motivation: Gaussian Process

Density Estimation

- Given data, estimate a probability density function that best explains it
- A nonparametric prior can be placed over an infinite set of distributions

Posterior:

Gaussian Process

Whiteboard:

– Parametric vs. Nonparametric learning
– High level idea of GP regression
– GP Regression
  • Example prior
  • Strawman inference algorithm
  • Example posterior
– GP Classification
  • approximate inference
  • Example posterior
Background: Multivariate Gaussians

Whiteboard:

– Marginal of multivariate Gaussian
– Conditional of multivariate Gaussian
Gaussian Process Regression

**Whiteboard:**

– Function-space view
  - definition of Gaussian Process
  - mean function
  - covariance function

– Example kernels

– Weight-space view
  - linear regression (linear model + Gaussian noise)
  - ridge regression (adding a Gaussian prior)
  - Bayesian linear regression
  - Bayesian kernel regression (aka. GP Regression)
Gaussian Process Regression

Whiteboard:

- MBR Decoding
- Computational complexity
GAUSSIAN PROCESS INFERENACE
Gaussian Process Example

Posterior (kernel: 1**2 * RBF(length_scale=1))
Log-Likelihood: -1.419
Gaussian Process Example

Posterior (kernel: 0.728**2 * RBF(length_scale=1.6))
Log-Likelihood: -2.084
Gaussian Process Example

Posterior (kernel: $1.49^2 \times \text{RBF}(\text{length}_\text{scale}=0.528))$
Log-Likelihood: -5.463