Semi-supervised Learning

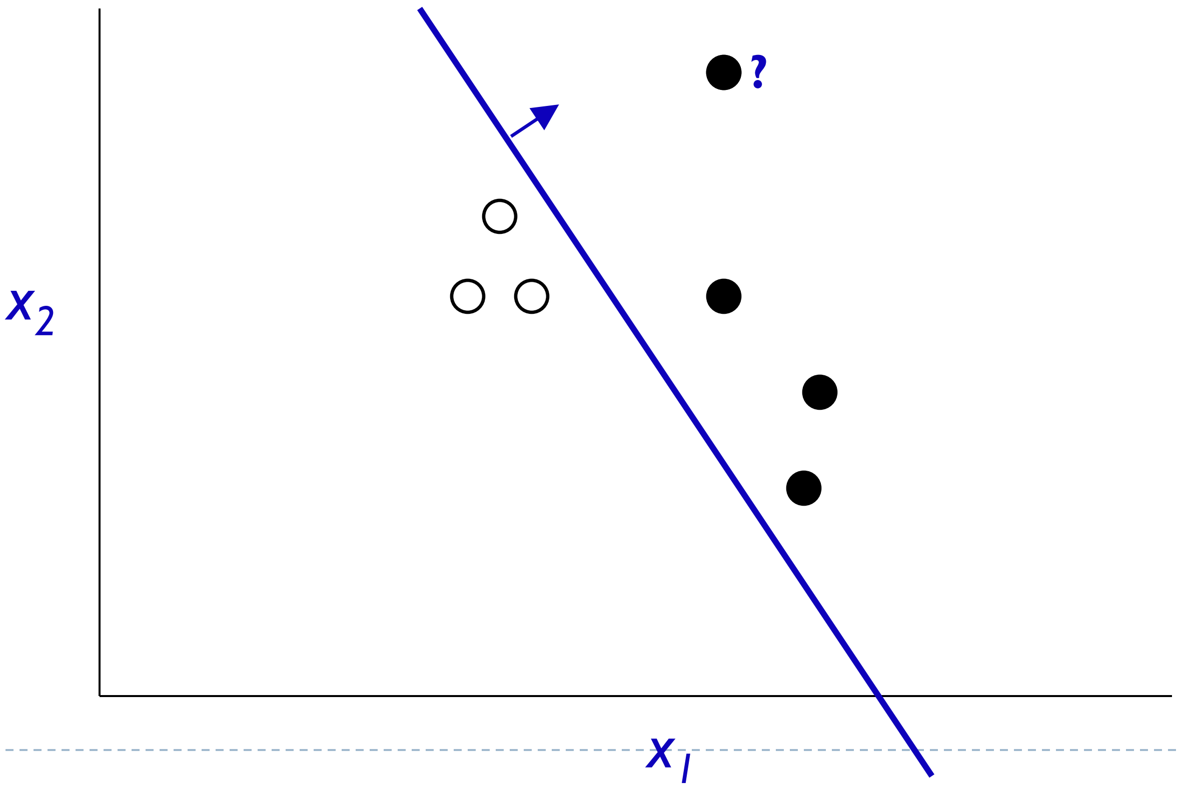
EECS 395/495 Probabilistic Graphical Models
Fall 2014

Semi-supervised Learning

- Unlabeled data abounds in the world
  - Web, measurements, etc.
- *Labeled* data is expensive
  - Image classification, natural language processing, speech recognition, etc. all require large #s of labels
- Idea: use unlabeled data to help with learning

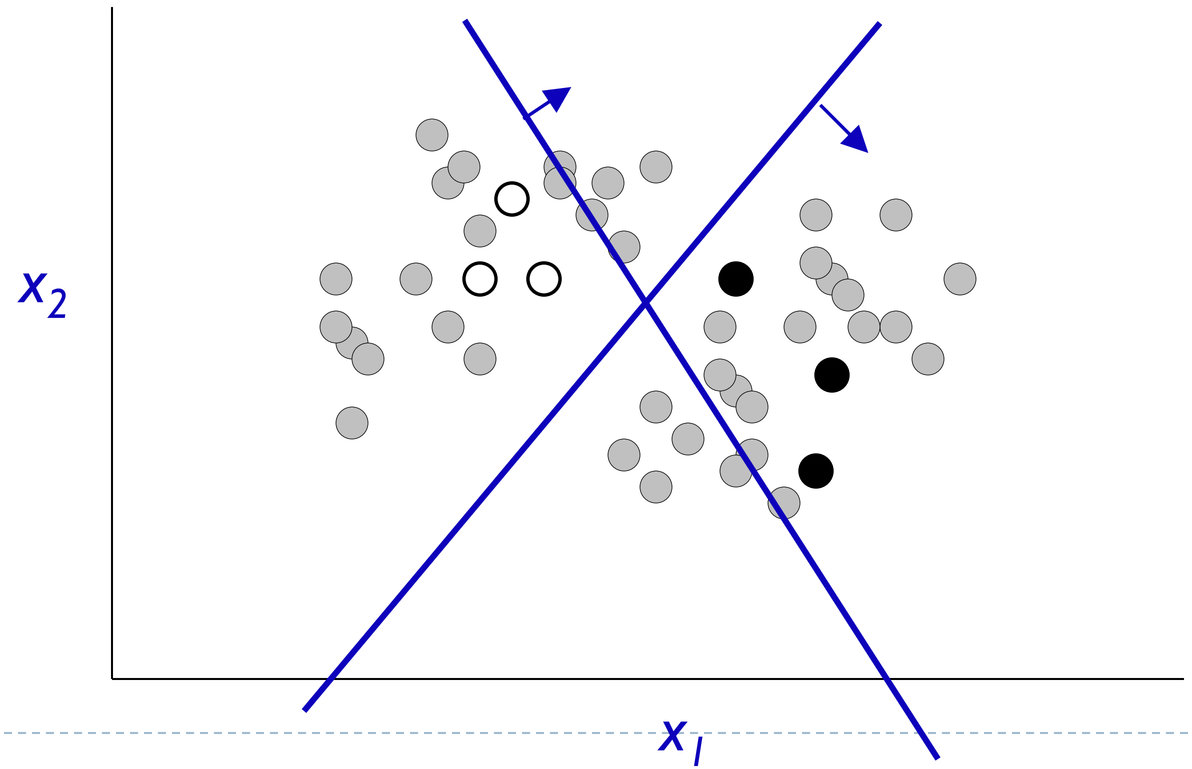
Supervised Learning

Learn function from $\mathbf{x} = (x_1, \ldots, x_d)$ to $y \in \{0, 1\}$
given labeled examples $(\mathbf{x}, y)$



Semi-supervised Learning (SSL)

Learn function from $\mathbf{x} = (x_1, \ldots, x_d)$ to $y \in \{0, 1\}$
given labeled examples $(\mathbf{x}, y)$
and unlabeled examples $(\mathbf{x})$



SSL in Graphical Models

- Graphical Model describes how data (***x***, y) is generated
- Missing Data: *y*
- So use EM

Example: Document classification with Naïve Bayes

$$P(x_i|\theta) = \sum_{j\in[M]} P(c_j|\theta)P(x_i|c_j;\theta).$$

- x_i = count of word *i* in document
- c_j = document class (sports, politics, etc.)
- x_{it} = count of word *i* in docs of class *t*

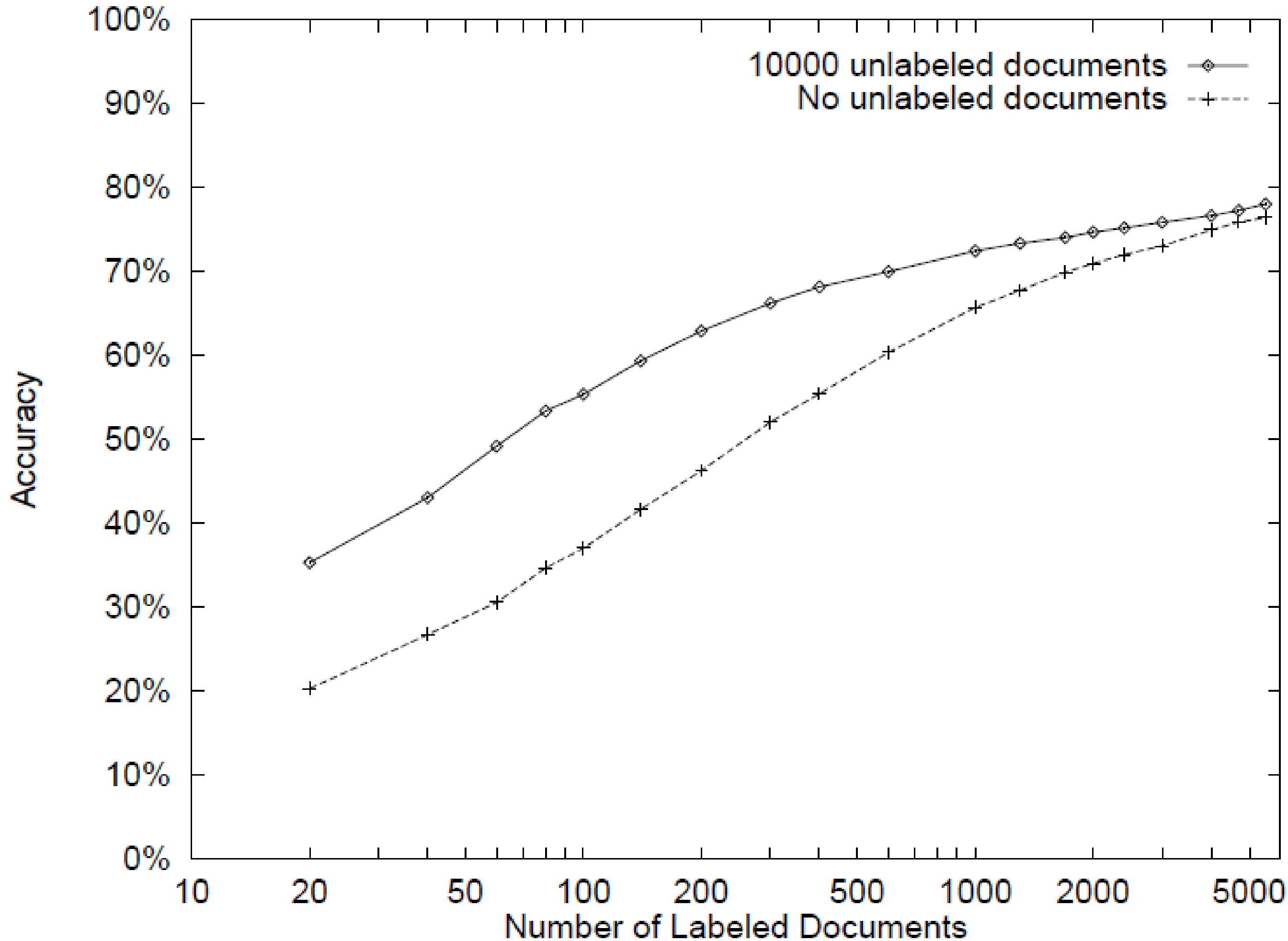
$$P(x_i|\theta) \propto P(|x_i|) \sum_{j\in[M]} P(c_j|\theta) \prod_{w_t\in\mathcal{X}} P(w_t|c_j;\theta)^{x_{it}}$$

- *M* classes, *W* = $|\mathcal{X}|$ words
- (from *Semi-supervised Text Classification Using EM*, Nigam, et al.)

Semi-supervised Training

- Initialize θ ignoring missing data
- E-step:
  - $E[x_{it}]$ = count of word i in docs of class t in training set
    + E_θ[count of word i in docs of class t in unlabeled data]
  - $E[\#c_t]$ = count of docs in class t in training
    + E_θ[count of docs of class t in unlabeled data]
- M-step:
  - Set θ according to expected statistics above, I.e.:
    - $P_\theta(w_t \mid c_t) = (E[x_{it}] + 1) / (W + \Sigma_i E[x_{it}])$
    - $P_\theta(c_t) = (E[\#c_t] + 1) / (\#\text{tokens} + M)$

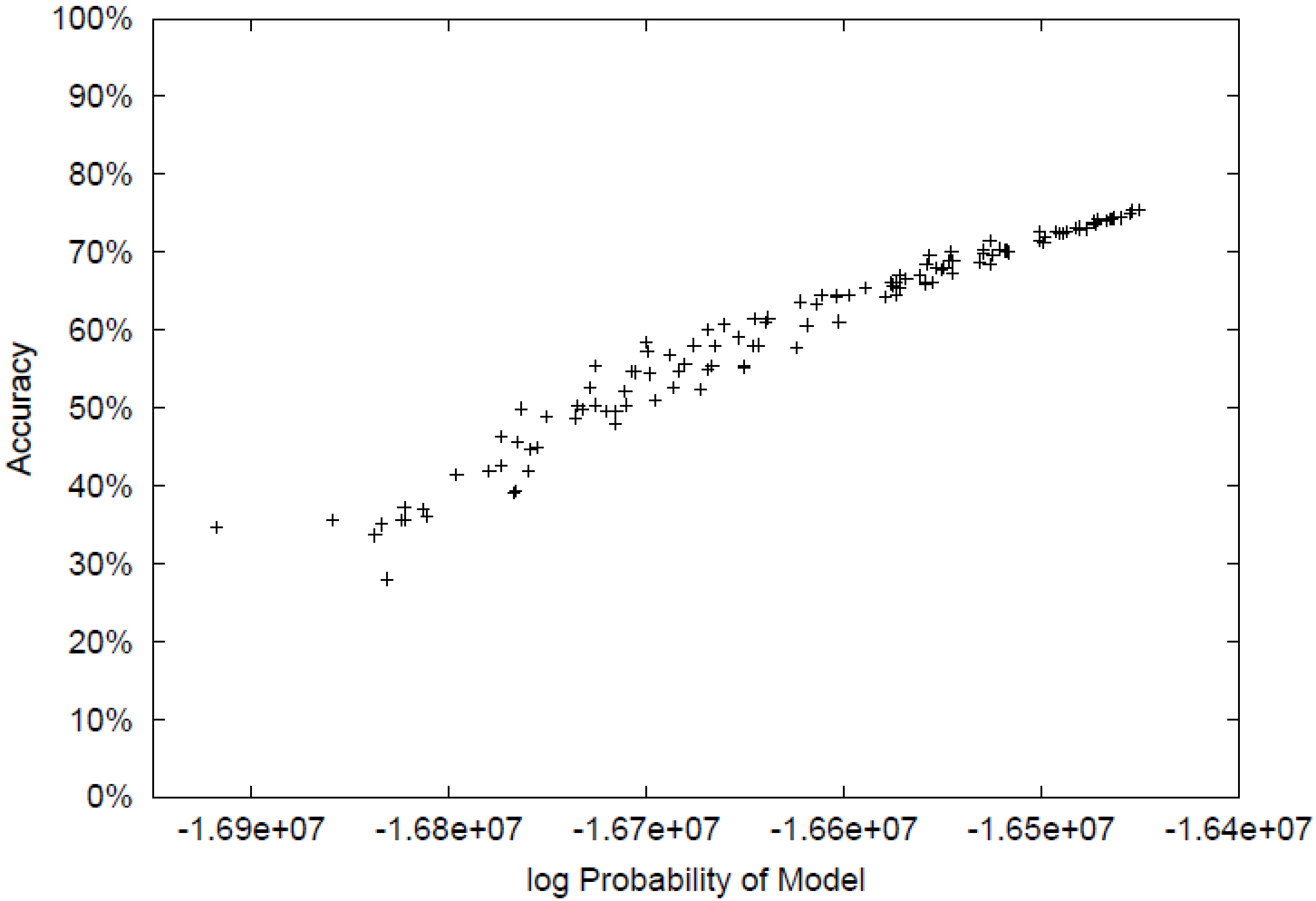
Semi-supervised Learning



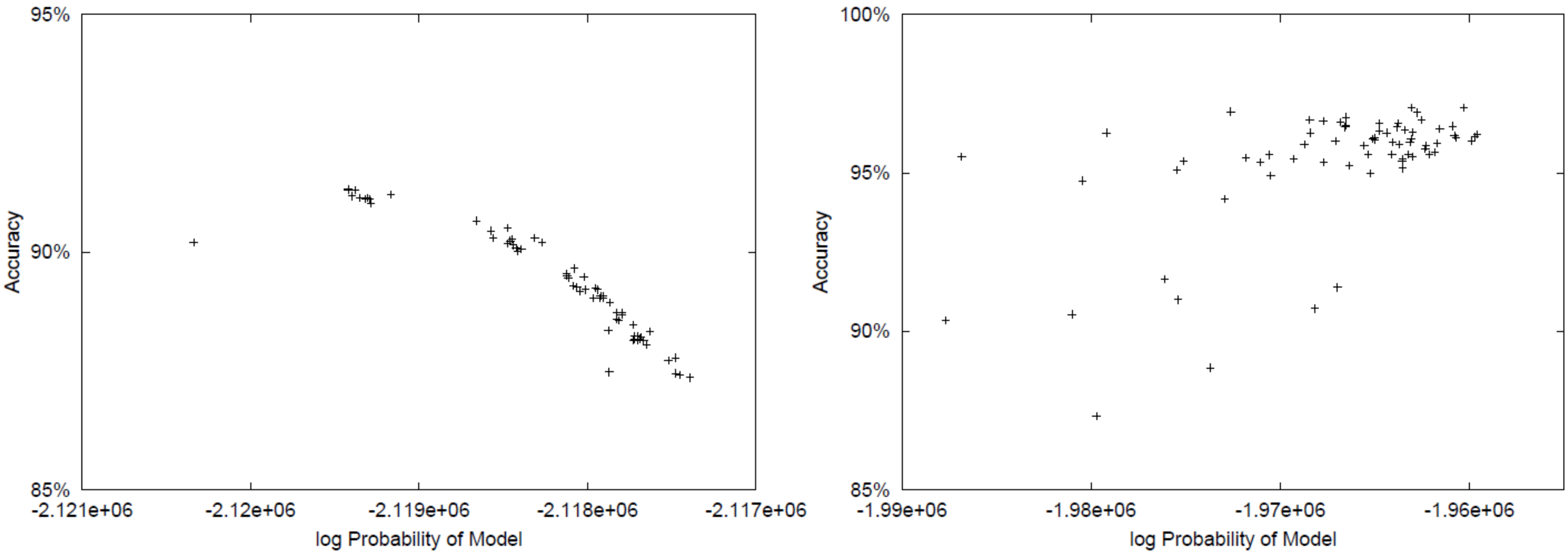
When does semi-supervised learning work?

- When a better model of $P(\boldsymbol{x})$ => better model of $P(y \mid \boldsymbol{x})$
- Can't use purely *discriminative* models
- Accurate modeling assumptions are key
  - Consider: *negative* class

Good example



Issue: negative class



Negative

- NB*, EM* represent the negative class with the optimal number of model classes (c_i's)

Category	NB1	EM1	NB*	EM*
acq	86.9	81.3	88.0 (4)	**93.1** (10)
corn	94.6	93.2	96.0 (10)	**97.2** (40)
crude	94.3	94.9	95.7 (13)	**96.3** (10)
earn	94.9	95.2	**95.9** (5)	95.7 (10)
grain	94.1	93.6	96.2 (3)	**96.9** (20)
interest	91.8	87.6	95.3 (5)	**95.8** (10)
money-fx	93.0	90.4	94.1 (5)	**95.0** (15)
ship	94.9	94.1	**96.3** (3)	95.9 (3)
trade	91.8	90.2	94.3 (5)	**95.0** (20)
wheat	94.0	94.5	96.2 (4)	**97.8** (40)

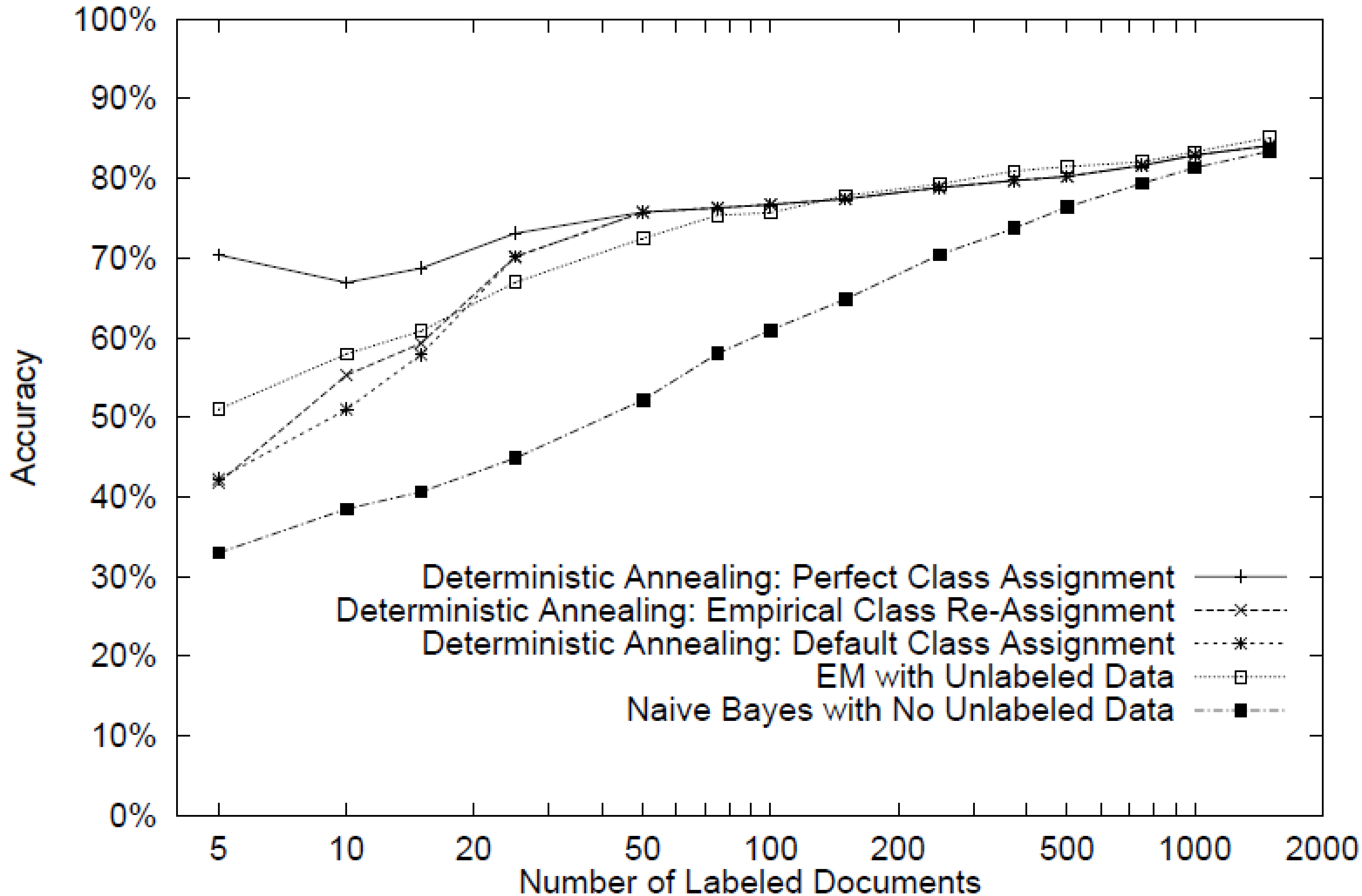
Problem: local maxima

- "Deterministic Annealing"

$$l(\theta|X,Y) = \sum_{x_i \in X_u} \log \sum_{c_j \in [M]} [\mathrm{P}(c_j|\theta)\mathrm{P}(x_i|c_j;\theta)]^\beta + \sum_{x_i \in X_l} \log([\mathrm{P}(y_i = c_j|\theta)\mathrm{P}(x_i|y_i = c_j;\theta)]^\beta)$$

- Slowly increase β
- Results: works, but can end up confusing classes (next slide)

Annealing performance



Homework #4 (1 of 3)

- What if we don't know the target classes in advance?
- Example: Set Expansion

  - Wait until query time to run EM? Slow.

- Strategy: Learn a model in advance, obtain mapping from examples => "classes"

- Then at "query time" compare examples

Homework #4 (2 of 3)

- Classify noun phrases based on *context* in text
  - E.g. `____ prime minister   CEO of ____`
- Model noun phrases (NPs) as P(*z* | *w*):

	z=1	2		N
P(z | Canada) =	0.14	0.01	…	0.06

- Experiment with *N*=4
- Query time
  - **Input**: "seeds" (e.g., Algeria, UK)
  - **Output**: ranked list of other NPs, using KL div.

Homework #4 (3 of 3)

- Code: written in Java
- You write ~4 lines
  - (important ones)
- Run some experiments

Road Map

- Basics of Probability and Statistical Estimation
- Bayesian Networks
- Markov Networks
- Inference
- Learning
  - Parameters, Structure, EM
- **HMMs**