USING CLASSIFIER CASCADES FOR SCALABLE E-MAIL CLASSIFICATION

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Building a scalable e-mail system

- **Goal:** Maintain system throughput across conditions
- **Varying conditions**
  - Load varies
  - Resource availability varies
  - Task varies
- **Challenge:** Build a system that can adapt its operation to the conditions at hand
Problem structure informs scalable solution

Feature Structure

- IP
- Mail From
- Subject
- Body

Derived features

Class Structure

- Ham
  - Business
  - Personal
- Spam
  - Social Network
  - Newsgroup

Granularity

Cost

$ $

$ $$$
Important facets of problem

- **Structure in input**
  - Features may have an order or systemic dependency
  - Acquisition costs vary: cheap or expensive features

- **Structure in output**
  - Labels naturally have a hierarchy from coarse-to-fine
  - Different levels of hierarchy have different sensitivities to cost

- Exploit structure during classification

- Minimize costs, minimize error
Two overarching questions

- When should we acquire features to classify a message?
- How does this acquisition policy change across different classification tasks?

- Classifier Cascades can answer both questions!
Introducing Classifier Cascades

- Series of classifiers: \( f_1, f_2, f_3 \ldots f_n \)
Introducing Classifier Cascades

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- Each classifier operates on different, increasingly expensive sets of features ($\phi$) with costs $c_1, c_2, c_3 \ldots c_n$
Introducing Classifier Cascades

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• Each classifier operates on different, increasingly expensive sets of features \((\phi)\) with costs \(c_1, c_2, c_3 \ldots c_n\)

• Classifier outputs a value in \([-1,1]\), the margin or confidence of decision
Introducing Classifier Cascades

• Series of classifiers: $f_1, f_2, f_3 \ldots f_n$
• Each classifier operates on different, increasingly expensive sets of features ($\phi$) with costs $c_1, c_2, c_3 \ldots c_n$
• Classifier outputs a value in $[-1,1]$, the margin or confidence of decision
• $\gamma$ parameters control the relationship of classifiers
Optimizing Classifier Cascades

- Loss function: \( L(y, F(x)) \) – errors in classification

- Minimize loss function, incorporating cost
  - Cost-constraint with budget (load-sensitive):
    \[
    \min \sum_{(x,y) \in D} L(y, F(x)) \text{ s.t. } C(x) < B
    \]
  - Cost Sensitive loss function (granular):
    \[
    \min \sum_{(x,y) \in D} L(y, F(x)) + \lambda C(x)
    \]

- Use grid-search to find optimal \( \gamma \) parameters
Load-Sensitive Classification
Features have costs & dependencies

IP is known at socket connect time, is 4 bytes in size
Features have costs & dependencies

The Mail From is one of the first commands of an SMTP conversation. From addresses have a known format, but higher diversity.
The subject, one of the mail headers, occurs after a number of network exchanges. Since the subject is user-generated, it is very diverse and often lacks a defined format.
Load-Sensitive Problem Setting

- Train IP, MailFrom, and Subject classifiers
- For a given budget, $B$, choose $\gamma_1, \gamma_2$ that minimize error within $B$
- Constraint: $C(x) < B$
Load-Sensitive Challenges

- Overfitting model when choosing $\gamma_1, \gamma_2$
- Train-time costs underestimated versus test-time performance
- Use a regularization constant $\Delta$
  - Sensitive to cost variance ($\sigma$)
  - Accounts for variability
- Revised constraint: $C(x) + \Delta \sigma < B$
Granular Classification
E-mail Challenges: Spam Detection

- Most mail is spam
- Billions of classifications
- Must be incredibly fast
E-mail Challenges: Categorizing Mail

• E-mail does more, tasks such as:
  • Extract receipts, tracking info
  • Thread conversations
  • Filter into mailing lists
  • Inline social network response

• Computationally intensive processing
• Each task applies to one class
Coarse task is constrained by feature cost

Feature Structure
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- Newsgroup

Cost
-$-

Granularity

Cost

$$$
Fine task is constrained by misclassification cost
Granular Classification Problem Setting

- Two separate models for different tasks, with different classifiers and cascade parameters
- Choose $\gamma_1, \gamma_2$ for each cascade to balance accuracy and cost with different tradeoffs $\lambda$
Experimental Results
Experimental Setup: Overview

- Two tasks: load-sensitive & granular classification
- Two datasets: Yahoo! Mail corpus and TREC-2007
  - Load-sensitive uses both datasets, granular uses only Yahoo!
- Results are L1O, 10-fold CV with bold values significant (p<.05)
- Cascade stages use MEGAM MaxEnt classifier
**Experimental Setup: Yahoo! Data**

- Data from 1227 Yahoo! Mail messages from 8/2010
- Feature costs calculated from network + storage cost

<table>
<thead>
<tr>
<th>Class</th>
<th>Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spam</td>
<td>531</td>
</tr>
<tr>
<td>Business</td>
<td>187</td>
</tr>
<tr>
<td>Social Network</td>
<td>223</td>
</tr>
<tr>
<td>Newsletter</td>
<td>174</td>
</tr>
<tr>
<td>Personal/Other</td>
<td>102</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP</td>
<td>.168</td>
</tr>
<tr>
<td>MailFrom</td>
<td>.322</td>
</tr>
<tr>
<td>Subject</td>
<td>.510</td>
</tr>
</tbody>
</table>
Experimental Setup: TREC data

- Data from TREC-2007 Public Spam Corpus, 47194 messages
- Use same feature cost estimates

<table>
<thead>
<tr>
<th>Class</th>
<th>Messages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spam</td>
<td>39055</td>
</tr>
<tr>
<td>Ham</td>
<td>8139</td>
</tr>
</tbody>
</table>
Results: Load-Sensitive Classification

Regularization prevents cost excesses

<table>
<thead>
<tr>
<th>$\Delta$</th>
<th>Y!Mail</th>
<th>TREC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>.115</td>
<td>.059</td>
</tr>
<tr>
<td>.25</td>
<td>.020</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Average excess cost

Classification Cost vs. Classification Budget

Y!Mail Dataset
Results: Load-Sensitive Classification

Significant error reduction

Classification Error across methods in different datasets

Dataset

Classification Error ($L(x)$)

Naive
ACC, $\Delta=0$
ACC, $\Delta=.25$
ACC, $\Delta=.5$
## Results: Granular Classification

<table>
<thead>
<tr>
<th>Feature Set</th>
<th>Feature Cost</th>
<th>Misclass Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse</td>
<td>Fine</td>
</tr>
<tr>
<td>Fixed: IP</td>
<td>.168</td>
<td>.139</td>
</tr>
<tr>
<td>ACC: $\lambda_c=1.5$, $\lambda_f=1$</td>
<td>.187</td>
<td>.140</td>
</tr>
<tr>
<td>Fixed: IP+MailFrom</td>
<td>.490</td>
<td>.128</td>
</tr>
<tr>
<td>ACC: $\lambda_c=.1$, $\lambda_f=.075$</td>
<td>.431</td>
<td>.111</td>
</tr>
<tr>
<td>Fixed: IP+MailFrom+Subject</td>
<td>1.00</td>
<td>.106</td>
</tr>
<tr>
<td>ACC: $\lambda_c=.02$, $\lambda_f=.02$</td>
<td>.691</td>
<td>.108</td>
</tr>
</tbody>
</table>

- Compare fixed feature acquisition policies to adaptive classifiers
- Significant gains in performance or cost (or both) depending on tradeoff
Dynamics of choosing $\lambda_c$ and $\lambda_f$
Different approaches, same tradeoff
Conclusion

- Problem of scalable e-mail classification
- Introduce two settings
  - Load-sensitive Classification: known budget
  - Granular Classification: task sensitivity
- Use classifier cascades to achieve tradeoff between cost and accuracy
- Demonstrate results superior to baseline

Questions?

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