A Pruned Problem Transformation Method for Multi-label Classification

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Outline

- Single-label classification
- Multi-label classification
- Problem Transformation
  - Binary Method
  - Combination Method
- PPT: A Pruned Problem Transformation method
- Experiments I
- PPT-ext: PPT extended
- Experiments II
- Summary

Single-label (Multi-class) Classification

- Set of documents D. Set of labels L.
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Applications of ML Classification

Using Machine Learning to train from manually multi-labelled documents, and learn to automatically classify new documents with multi-labels (AKA ‘tags’).

- News articles
- Encyclopedia articles
- Academic papers (categories, key words)
- Emails
- Internet forum posts
- Web pages (as bookmarks, web directories)
- RSS feeds
- Biological applications (genes, etc. . .)

Problem Transformation

Single-label classification:

- Analyse a document, make a classification.

Multi-label classification:

- Analyse a document, . . . ?
- Solution 1.: Make several (single-label) decisions
- Solution 2.: Make one (single-label) decision involving multiple labels
- This involves: Transforming a multi-label problem into one or more single-label problems (and back again) **i.e. Problem Transformation**.

Solution 1. Binary Method

Several single-label classifiers make several binary decisions (a label is relevant, or $\neg$relevant (1/0)).

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Multi-label D_{train}; $(d, S \subseteq L)$
d_1,{$Sports$,$Politics$}
d_2,{$Science$,$Politics$}
d_3,{$Sports$}
d_4,{$Environment$,$Science$}

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Label set: $L = \{Sport, Environment, Science, Politics\}$

Single-label D_{train}; $(d, l \in \{0,1\})$			
C_{Sport}	$C_{Envir.}$	$C_{Science}$	$C_{Politics}$
$(d_1, 1)$	$(d_1, 0)$	$(d_1, 0)$	$(d_1, 1)$
$(d_2, 0)$	$(d_2, 0)$	$(d_2, 1)$	$(d_2, 1)$
$(d_3, 1)$	$(d_3, 0)$	$(d_3, 0)$	$(d_3, 0)$
$(d_4, 0)$	$(d_4, 1)$	$(d_4, 1)$	$(d_4, 0)$

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Single-label Test; $(d, l \in \{0, 1\})$			
C_{Sport}	$C_{Envir.}$	$C_{Science}$	$C_{Politics}$
$(d_x, ?)$	$(d_x, ?)$	$(d_x, ?)$	$(d_x, ?)$

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- Assumes that all labels are independent

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Label set: $L = \{Sport, Environment, Science, Politics\}$

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d_x,$\{Environment$,$Science\}$

- May generate many labels from a few examples
- Can only predict combinations seen in the training set

Initial Conclusions

- The Combination Method does best, because it incorporates information about the relationships between labels, e.g.:
  - label X may only ever occur by itself
  - labels X and Y may occur together often
  - labels X and Y may never occur together
- But, it. . .
  - often generates too many labels
  - becomes overwhelmed by so many labels
- How can we improve?
  - 90% of label combs. only found in 10% of the data
  - concentrate on the key label combinations!

Pruned Problem Transformation (PPT)

Prune away all examples with infrequent label subsets. e.g. 10 examples, 6 combinations:

Doc.	**Labels** ($S \subseteq L$)
d_1	{Sports,Science}
d_2	{Environment,Science,Politics}
d_3	{Sports}
d_4	{Environment,Science}
d_5	{Science}
d_6	{Sports}
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d_8	{Politics}
d_9	{Politics}
d_{10}	{Science}

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- Lost 20% of data. Can we save any of that data?

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Doc.	**Labels** ($S \subseteq L$)
d_1	{Sports,Science}
d_2	{Environment,Science,Politics}

- Lost 20% of data. Can we save any of that data?
- Yes. By splitting up S into more frequent sub*sub*sets

Pruned Problem Transformation (PPT)

Prune away all examples with infrequent label subsets. e.g. 10 examples, 6 combinations:

Doc.	Labels ($S \subseteq L$)
d_3	{Sports}
d_4	{Environment,Science}
d_5	{Science}
d_6	{Sports}
d_7	{Environment,Science}
d_8	{Politics}
d_9	{Politics}
d_{10}	{Science}

Doc.	Labels ($S \subseteq L$)
d_1	{Sports,Science}
d_1	{Sports}
d_1	{Science}
d_2	{Environment,Science,Politics}
d_2	{Environment,Science}
d_2	{Politics}

- Lost 20% of data. Can we save any of that data?
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Prune away all examples with infrequent label subsets. e.g. 10 examples, 6 combinations:

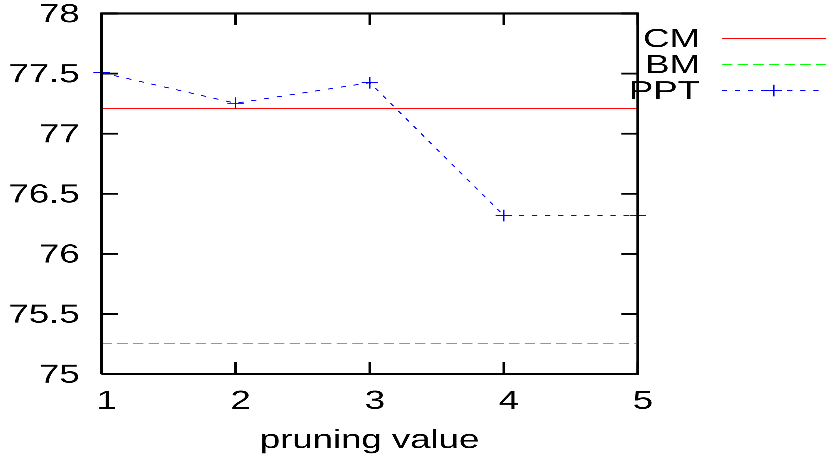
Doc.	**Labels** ($S \subseteq L$)
d_1	{Sports}
d_1	{Science}
d_2	{Environment,Science}
d_2	{Politics}
d_3	{Sports}
d_4	{Environment,Science}
d_5	{Science}
d_6	{Sports}
d_7	{Environment,Science}
d_8	{Politics}
d_9	{Politics}
d_{10}	{Science}

Pruned Problem Transformation (PPT)

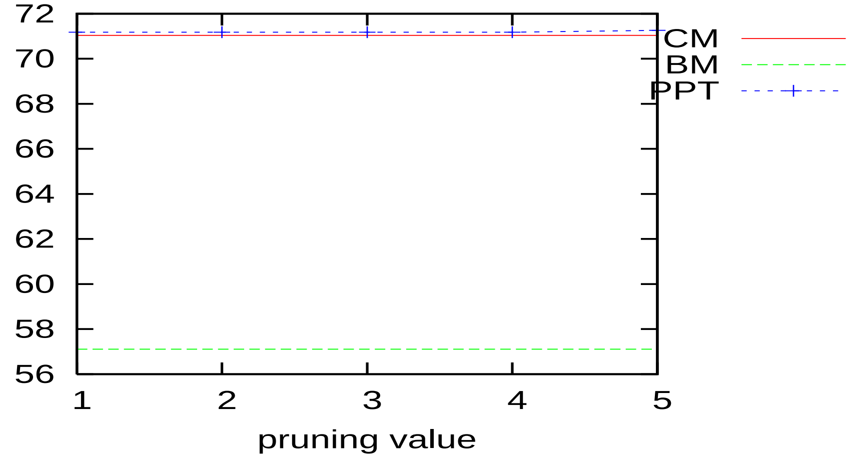
Prune away all examples with infrequent label subsets. e.g. 12 examples, 4 combinations:

Doc.	**Labels** ($S \subseteq L$)
d_1	{Sports}
d_1	{Science}
d_2	{Environment,Science}
d_2	{Politics}
d_3	{Sports}
d_4	{Environment,Science}
d_5	{Science}
d_6	{Sports}
d_7	{Environment,Science}
d_8	{Politics}
d_9	{Politics}
d_{10}	{Science}

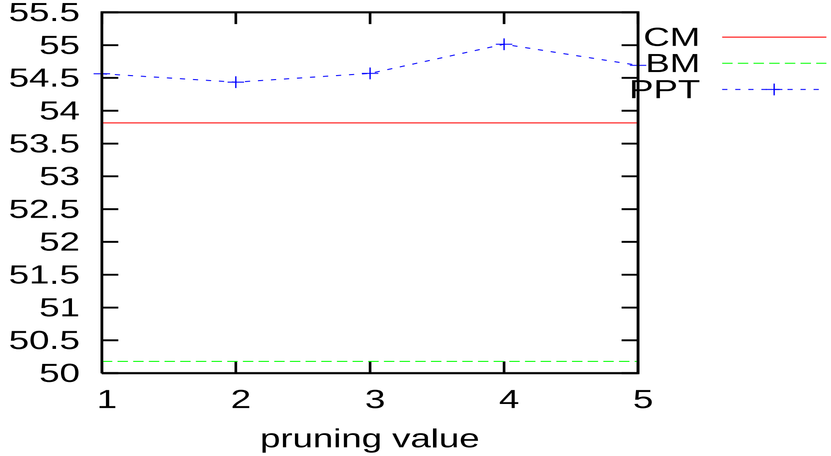
Experiments I. Accuracy.



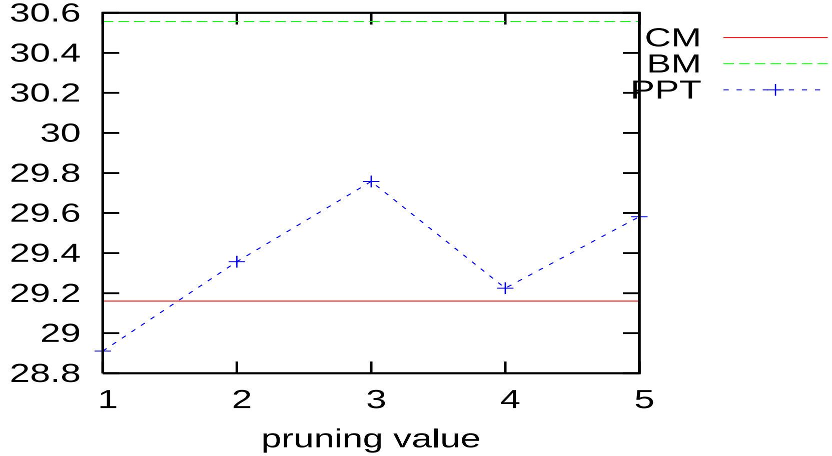
Medical Dataset



Scene Dataset

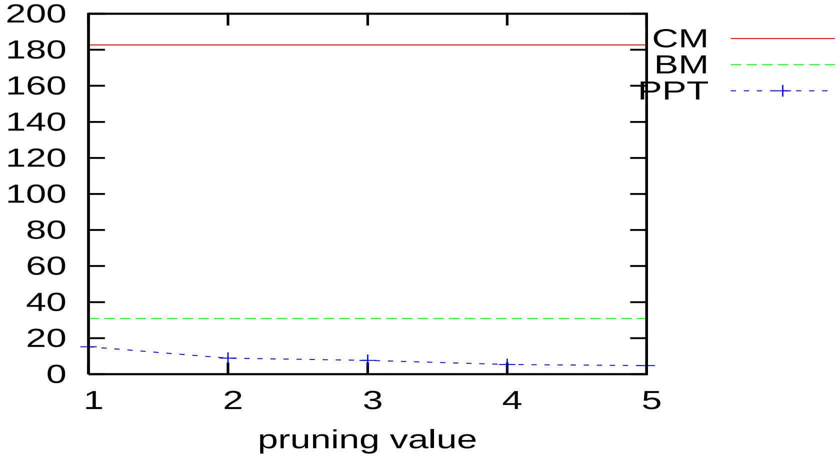


Yeast Dataset

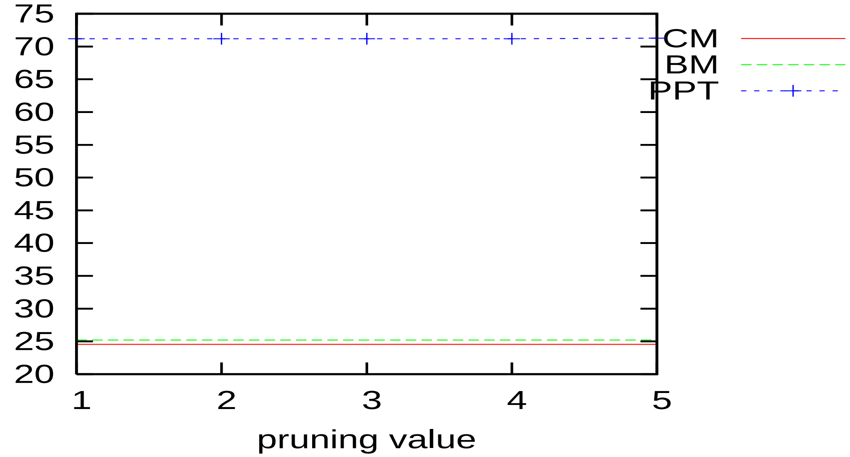


Enron Dataset

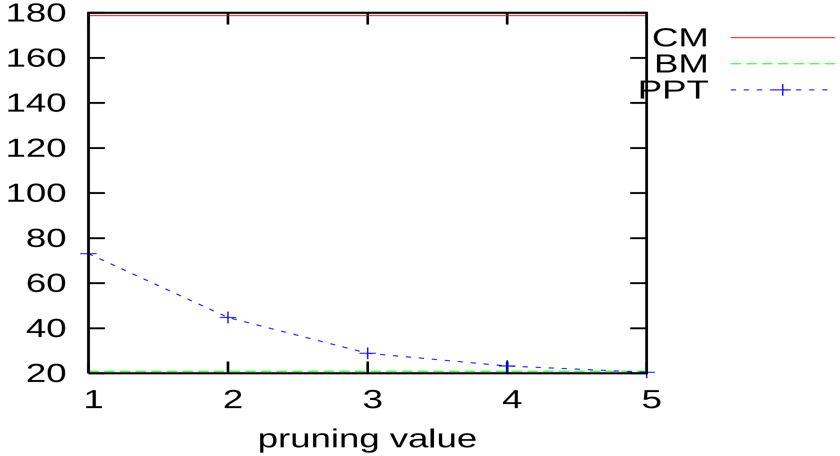
Experiments I. Build Time.



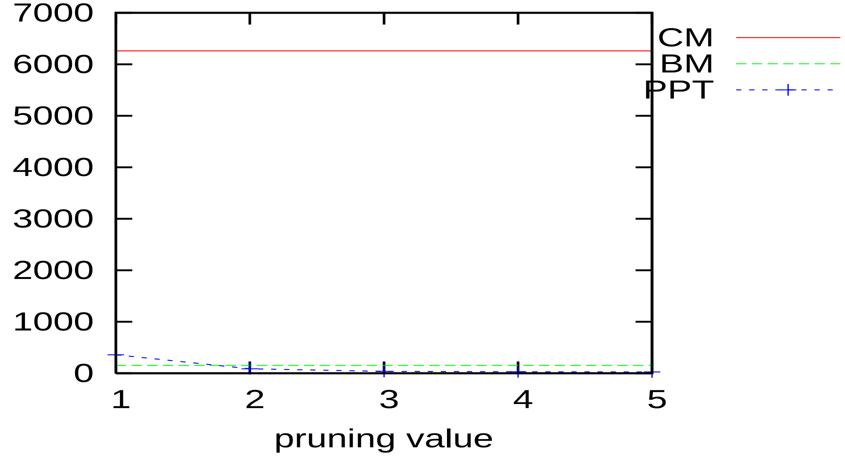
Medical Dataset



Scene Dataset



Yeast Dataset



Enron Dataset

PPT: Initial Conclusions

- Fast
- Superior to BM and CM for some pruning range
- . . . except Enron, where
  - labelling is very irregular (44% as many distinct label combinations as total examples)
  - PPT can't form new combinations
  - the Binary Method can (and *does better* because of this)
- The Binary Method combines several single labels to create a multi-label prediction
- Can we combine multiple labels to create *new multi-label predictions*?

PPT Extended (PPT-ext)

Yes–Given a test example d_x (about $Sports$ and $Science$) ...

- Look at a posterior P*robability* for each possible existing combination:

Combination (S)	$P(S\|d_x)$
$\{Sports, Politics\}$	0.2
$\{Science, Politics\}$	0.2
$\{Sports\}$	0.3
$\{Enviro., Science\}$	0.3

PPT Extended (PPT-ext)

Yes–Given a test example d_x (about $Sports$ and $Science$) ...

- Look at a posterior *Probability* for each possible existing combination:

Combination (S)	$P(S \mid d_x)$
$\{Sports, Politics\}$	0.2
$\{Science, Politics\}$	0.2
$\{Sports\}$	0.3
$\{Enviro., Science\}$	0.3

Label	Score
$Sports$	0.5
$Science$	0.5
$Politics$	0.4
$Enviro.$	0.3

- We can sum these probabilities for each label

PPT Extended (PPT-ext)

Yes–Given a test example d_x (about $Sports$ and $Science$) ...

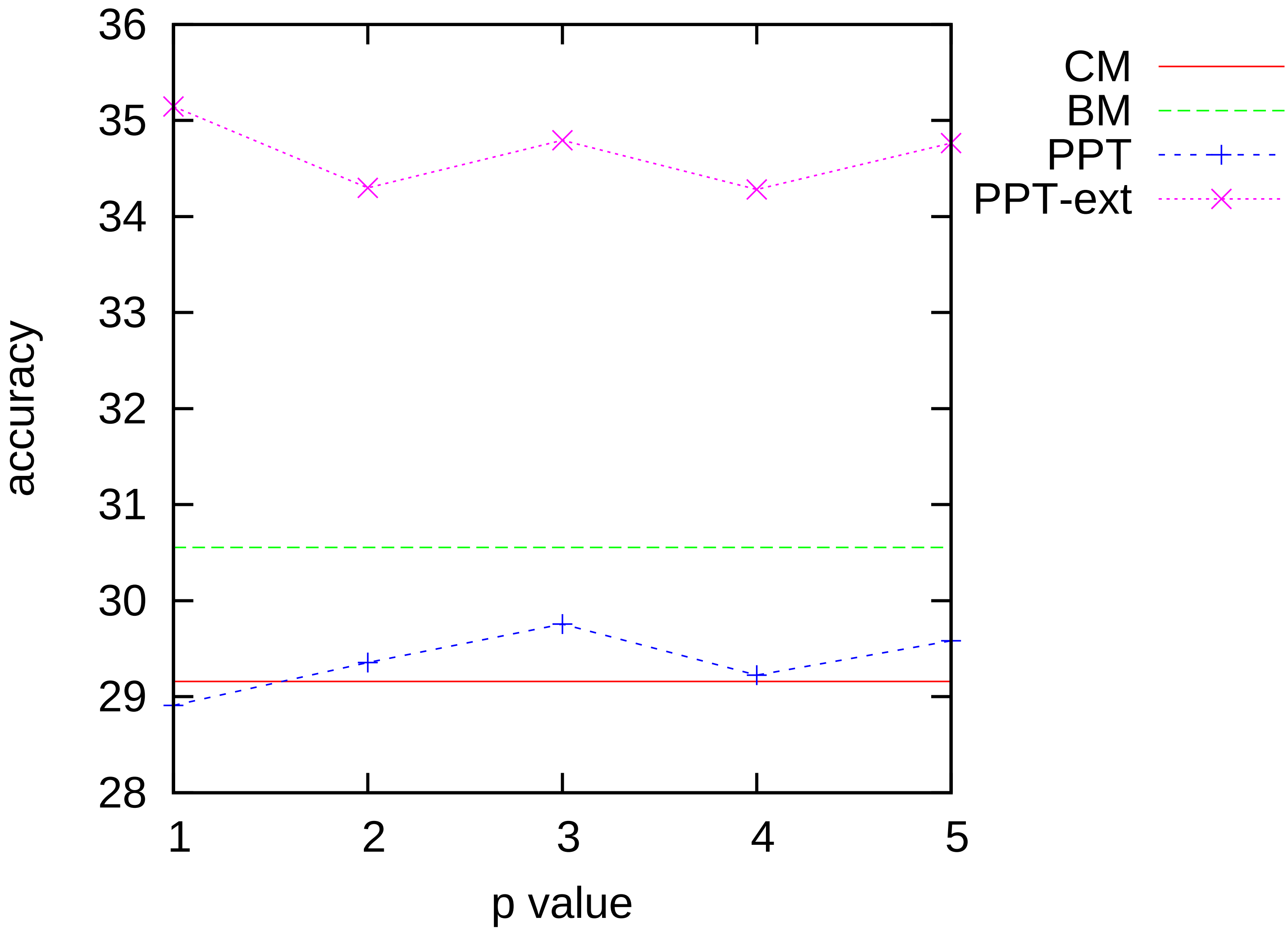
- Look at a posterior *Probability* for each possible existing combination:

Combination (S)	$P(S\|d_x)$
$\{Sports, Politics\}$	0.2
$\{Science, Politics\}$	0.2
$\{Sports\}$	0.3
$\{Enviro., Science\}$	0.3

Label	Score
$Sports$	0.5
$Science$	0.5
$Politics$	0.4
$Enviro.$	0.3

- We can sum these probabilities for each label
- Using a threshold of ≥ 0.5, gives us: $\{Sports, Science\}$

Experiments II. Accuracy



Enron Dataset. Accuracy (no change to build time!)

Summary

- Multi-label Classification via Problem Transformation
- Two standard approaches: CM, and BM
- CM: relationships between labels are important, but too many label combinations causes problems (and can't form new combinations)
- PPT: focus on key relationships
- PPT-ext: able to form new multi-label combinations
- Experiments: PPT and PPT-ext superior to CM and BM

Summary

- Multi-label Classification via Problem Transformation
- Two standard approaches: CM, and BM
- CM: relationships between labels are important, but too many label combinations causes problems (and can't form new combinations)
- PPT: focus on key relationships
- PPT-ext: able to form new multi-label combinations
- Experiments: PPT and PPT-ext superior to CM and BM

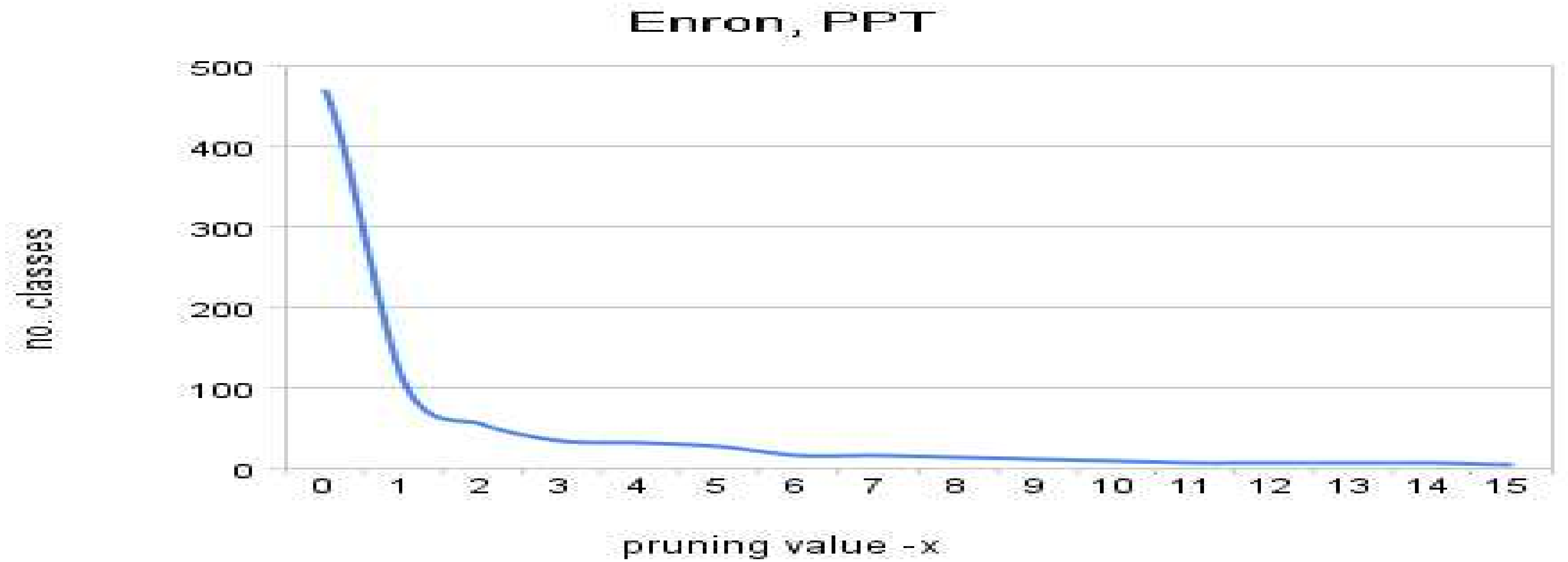
The End. – Questions? / Comments?

Appendix 1. Datasets

	$\|D\|$	$\|L\|$	$LCard(D)$	$PDist(D)$
Medical	978	45	1.25	0.096
Scene	2407	6	1.07	0.006
Yeast	2417	14	4.24	0.082
Enron	1702	53	3.38	0.442

$LCard(D)$ = average size of number of labels per document
$PDist(D)$ = the percentage of documents which are distinct

Appendix 2. Combination Popularity



Appendix 3. Evaluation

- Accuracy: $\frac{1}{|D|}\sum_{i=1}^{|D|}\frac{|S_i \cap Y_i|}{|S_i \cup Y_i|}$
- Hamming loss: $\frac{1}{|D|}\sum_{i=1}^{|D|}\frac{Y_i \Delta S_i}{|L|}$ (Δ = symmetrical difference)
- $F1$: $\frac{1}{|D|}\sum_{i=1}^{|D|}\frac{2*p*r}{p+r}$ ($p$recision,$r$ecall of Y_i from S_i)

E.g.:
$Y =$ `0100100010` (predicted)
$S =$ `0100101000` (actual)

Accuracy	$2/4$	0.50	(best = 1.00)
Hamming loss	$2/10$	0.20	(best = 0.00)
F1	$(2 * \frac{2}{3} * \frac{2}{3}/(\frac{2}{3} + \frac{2}{3}))$	0.67	(best = 1.00)

Appendix 4. Experiments III

	Medical		Enron	
	RAKEL	PPT	RAKEL	PPT
$F1$	0.776	0.789	0.457	0.503
Ham. Loss	0.012	0.011	0.067	0.074
Accuracy	0.743	0.776	0.323	0.353
McNemar's	$p = 0.295$		$p = 0.000$	
Build Time	190s	15s	3163s	195s
RAKEL par.	$m = 20, k = 27, t = .5$		$m = 80, k = 21, t = .5$	
PPT par.	$p = 1, -N_A$		$p = 5, -N_A, -J, t = .21$	

Appendix 5. Graph View

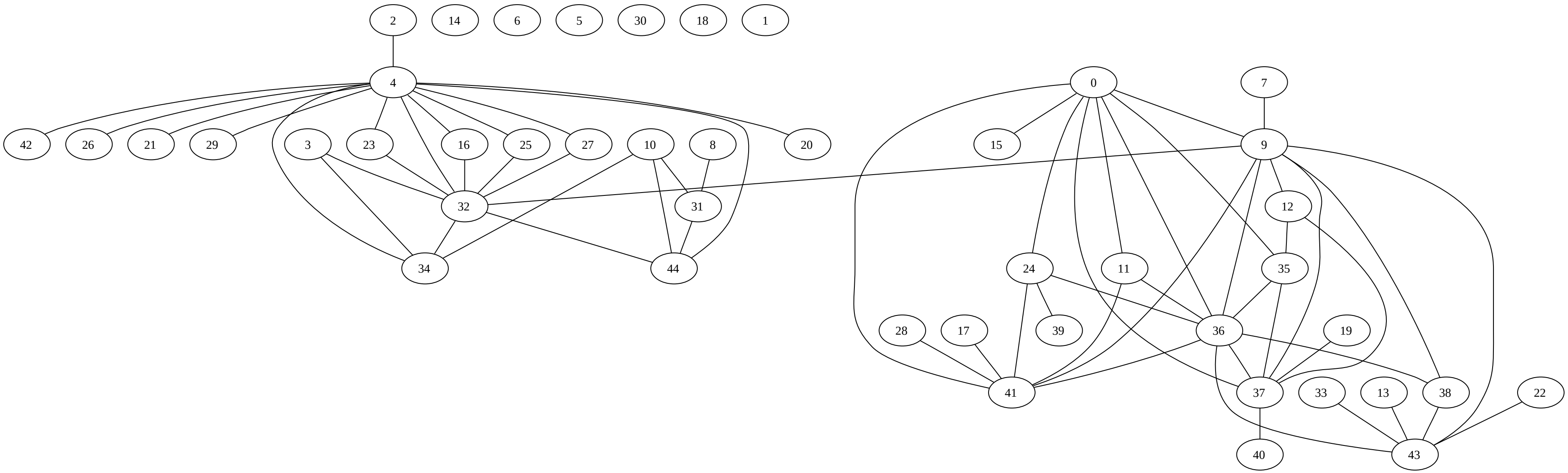


Figure 1: A multi-label dataset. Each node is a label. Each edge represents at least 1 co-occurrence of the two labels it connects

What if we ignore very infrequent co-occurrences between labels?

Appendix 5. Graph View

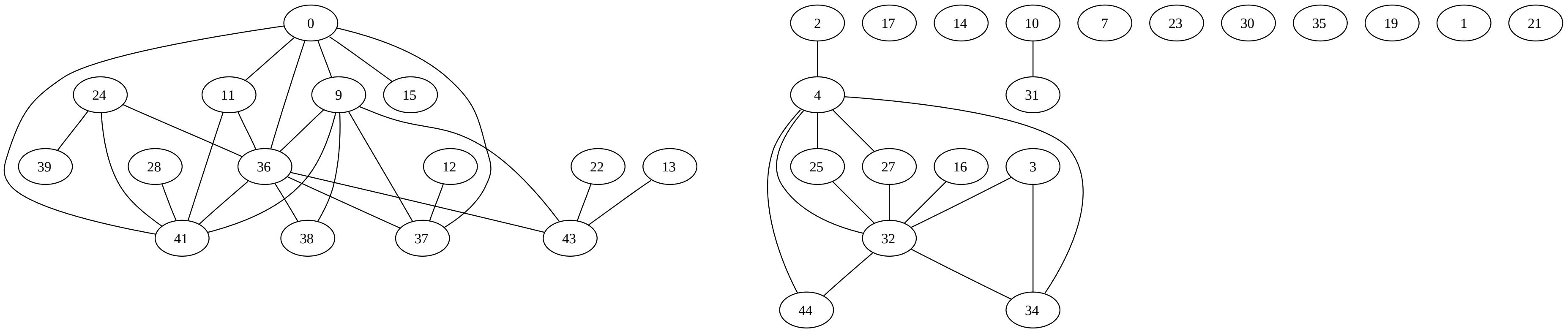


Figure 2: A multi-label dataset. Each node is a label. Each edge represents at least 2 co-occurrences of the two labels it connects (covers 97% of 978 examples)

Appendix 5. Graph View

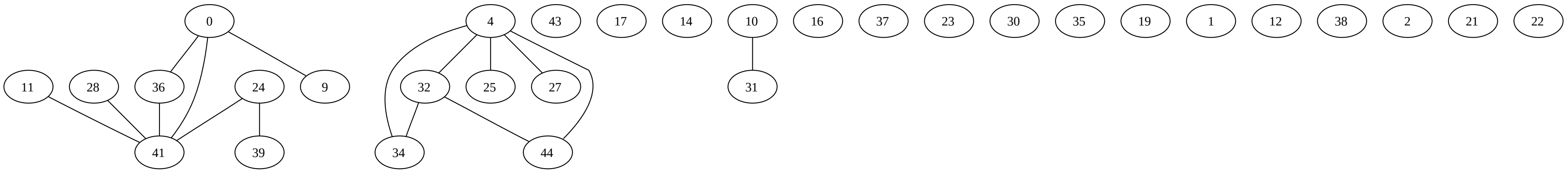


Figure 3: A multi-label dataset. Each node is a label. Each edge represents at least 3 co-occurrences of the two labels it connects (covers 92% of 978 examples)

These are the key label relationships.