Classification
&
Clustering

CS6200
Information Retrieval

Spam

Spam

Spam

```
To:  ...
From:  ...
Subject: non profit debt
X-Spam-Checked: This message probably not SPAM
X-Spam-Score: 3.853, Required: 5
X-Spam-Level: *** (3.853)
X-Spam-Tests: BAYES_50,DATE_IN_FUTURE_06_12,URIBL_BLACK
X-Spam-Report-rig: ---- Start SpamAssassin (v2.6xx-cscf) results
        2.0 URIBL_BLACK          Contains an URL listed in the URIBL blacklist
                                 [URIs: bad-debtyh.net.cn]
        1.9 DATE_IN_FUTURE_06_12   Date: is 6 to 12 hours after Received: date
        0.0 BAYES_50             BODY: Bayesian spam probability is 40 to 60%
                                 [score: 0.4857]

Say good bye to debt
Acceptable Unsecured Debt includes All Major Credit Cards, No-collateral
Bank Loans, Personal Loans,
Medical Bills etc.
http://www.bad-debtyh.net.cn
```

Spam

Website:

BETTING NFL FOOTBALL PRO FOOTBALL SPORTSBOOKS NFL FOOTBALL LINE ONLINE NFL SPORTSBOOKS NFL

Players Super Book

When It Comes To Secure NFL Betting And Finding The Best Football Lines Players Super Book Is The Best Option! Sign Up And Ask For 30 % In Bonuses.

MVP Sportsbook

Football Betting Has Never been so easy and secure! MVP Sportsbook has all the NFL odds you are looking for. Sign Up Now and ask for up to

30 % in Cash bonuses.

Term spam:

pro football sportsbooks nfl football line online nfl sportsbooks nfl football gambling odds online pro nfl betting pro nfl gambling online nfl football spreads offshore football gambling online nfl gamblibg spreads online football gambling line online nfl betting nfl sportsbook online online nfl betting spreads betting nfl football online online football wagering online gambling online gambling football online nfl football betting odds offshore football sportsbook online nfl football gambling ...

Link spam:

MVP Sportsbook Football Gambling Beverly Hills Football Sportsbook
Players SB Football Wagering Popular Poker Football Odds
Virtual Bookmaker Football Lines V Wager Football Spreads
Bogarts Casino Football Point Spreads Gecko Casino Online Football Betting
Jackpot Hour Online Football Gambling MVP Casino Online Football Wagering
Toucan Casino NFL Betting Popular Poker NFL Gambling
All Tracks NFL Wagering Bet Jockey NFL Odds
Live Horse Betting NFL Lines MVP Racebook NFL Point Spreads
Popular Poker NFL Spreads Bogarts Poker NFL Sportsbook ...

Sentiment

2,994 Reviews

5 star:	(1,204)
4 star:	(521)
3 star:	(480)
2 star:	(406)
1 star:	(383)

Average Customer Review
(2,994 customer reviews)

Most Helpful Customer Reviews

2,142 of 2,353 people found the following review helpful

Unexpected Direction, but Perfection (Potential spoilers, but pretty vague), August 24, 2010

By **A. R. Bovey** - See all my reviews

REAL NAME

Amazon Verified Purchase (What's this?)

This review is from: **Mockingjay (The Hunger Games, Book 3) (Hardcover)**

This was a brilliant conclusion to the trilogy. I can only compare it to "Ender's Game" - and that is extremely high praise, indeed.

When I first closed the book last night, I felt shattered, empty, and drained.

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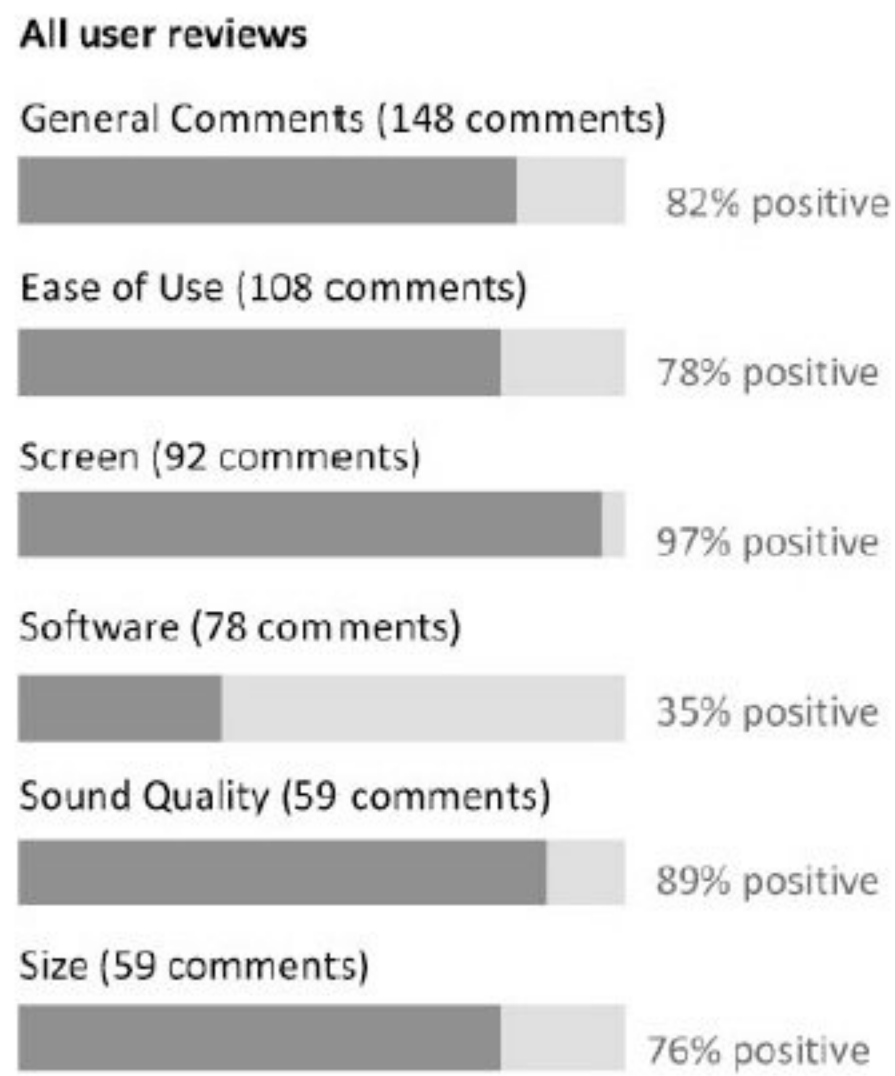
Maybe not so good if found in a camera review

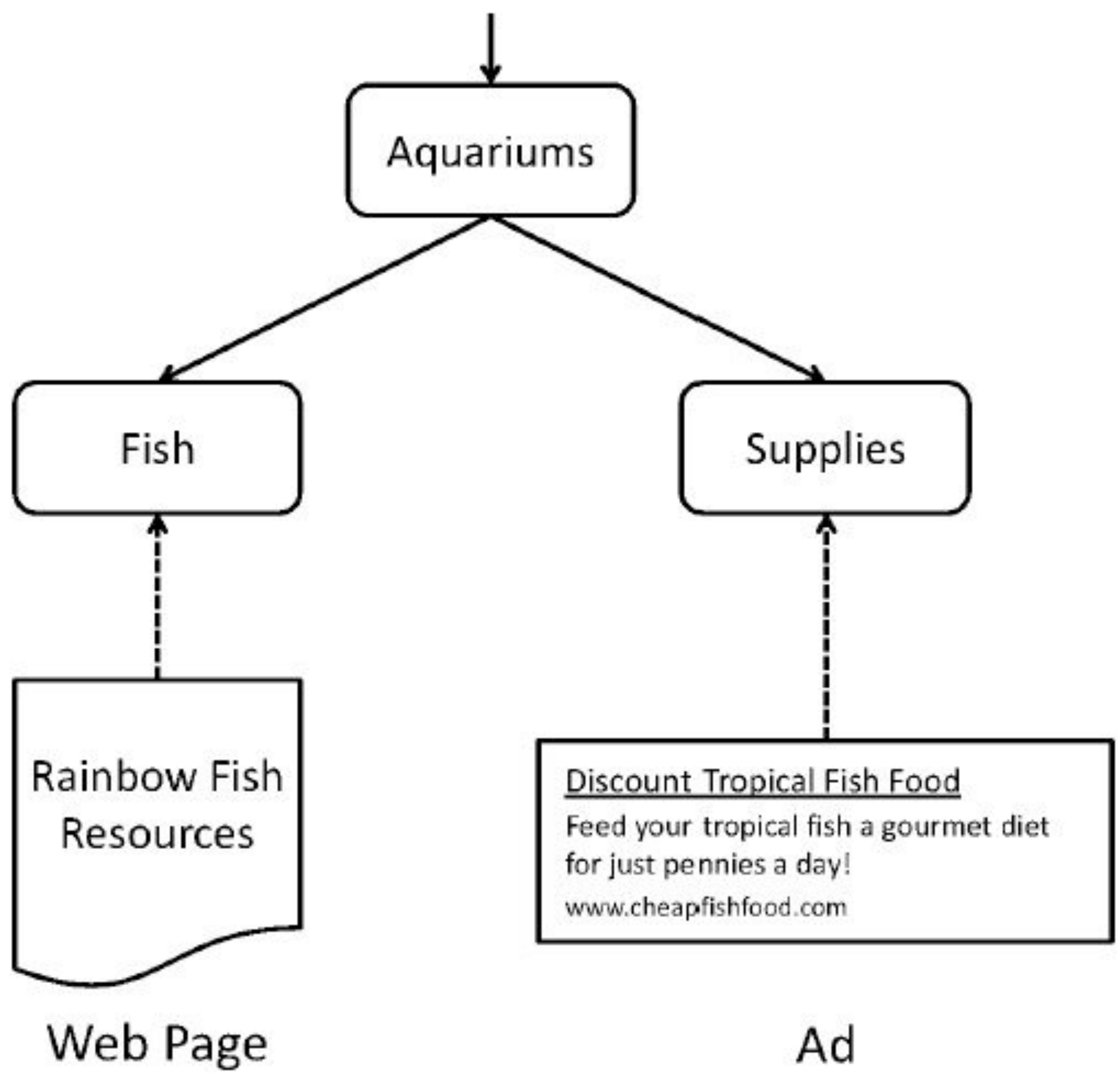
Sentiment


All user reviews
General Comments (148 comments)
82% positive
Ease of Use (108 comments)
78% positive
Screen (92 comments)
97% positive
Software (78 comments)
35% positive
Sound Quality (59 comments)
89% positive
Size (59 comments)
76% positive

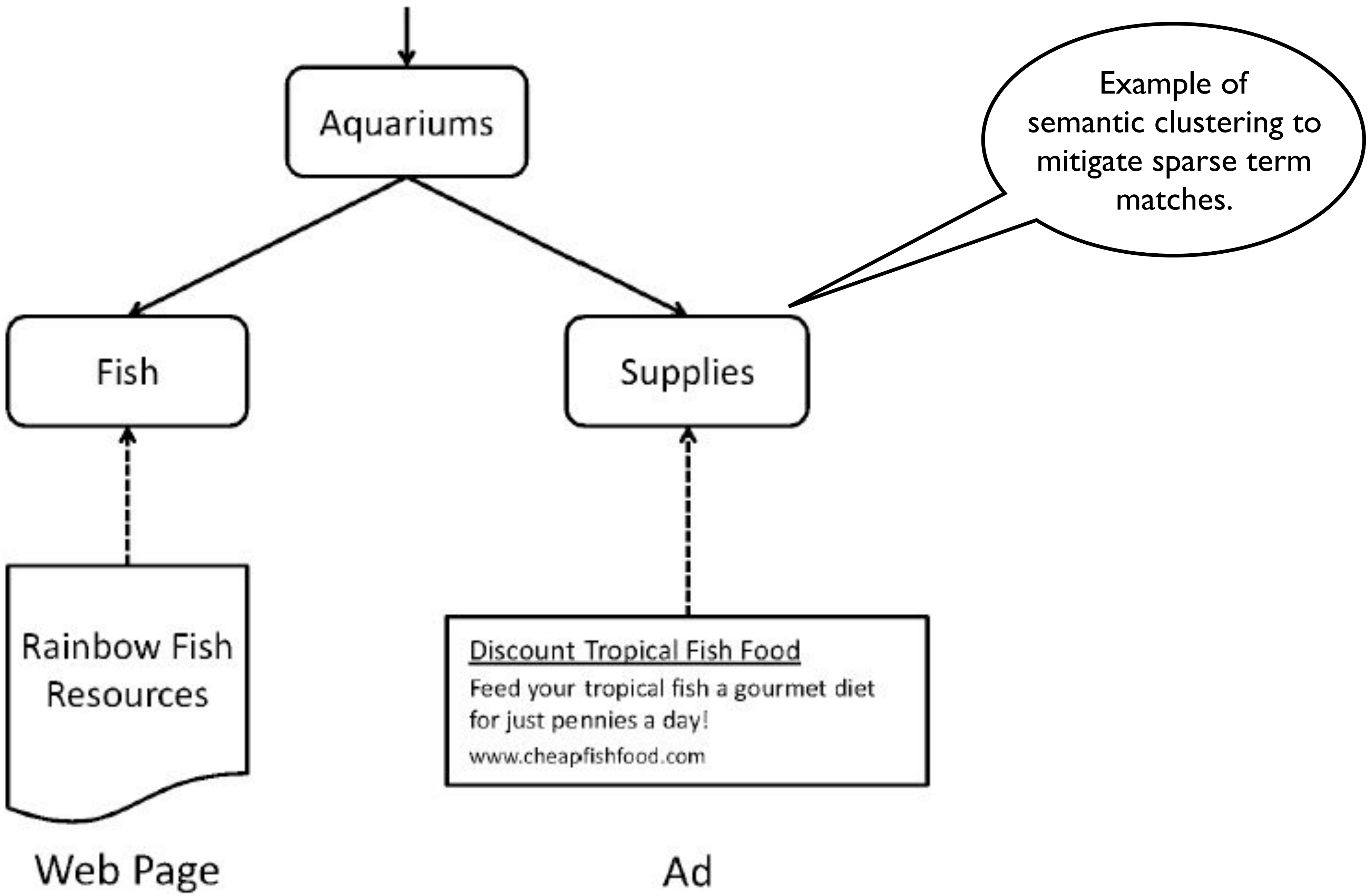
Advertising

- Search engines sell customer clicks from
  - Sponsored search
  - Content match
- Just retrieve ads topically like other docs?
  - Ads are very short and targeted
- Build specialized classifiers

Advertising



Advertising



Person Classification

Joseph Dwyer and David Smith headshots for Scientific American   Inbox x

Chin, Ann achin@sciam.com via cs.umass.edu   3:48 PM (3 minutes ago)

to jdwyer, dasmith

Drs. Dwyer and Smith,

I work in the photo department at Scientific American magazine and I'm requesting your headshots for your upcoming article. We need high resolution color photos that an artist can use as reference to turn your headshot into an illustration. An ideal shot would be from the shoulder up without hats or anything distracting your face. If the owner of the photograph requires a reference credit, please let us know (Please note that the actual photo will not be published.)

Can you please send your headshots by Wednesday, April 18?

Thanks,
Annie

...

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Thanks,
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I don't have a *Scientific American* article coming out.

Classification

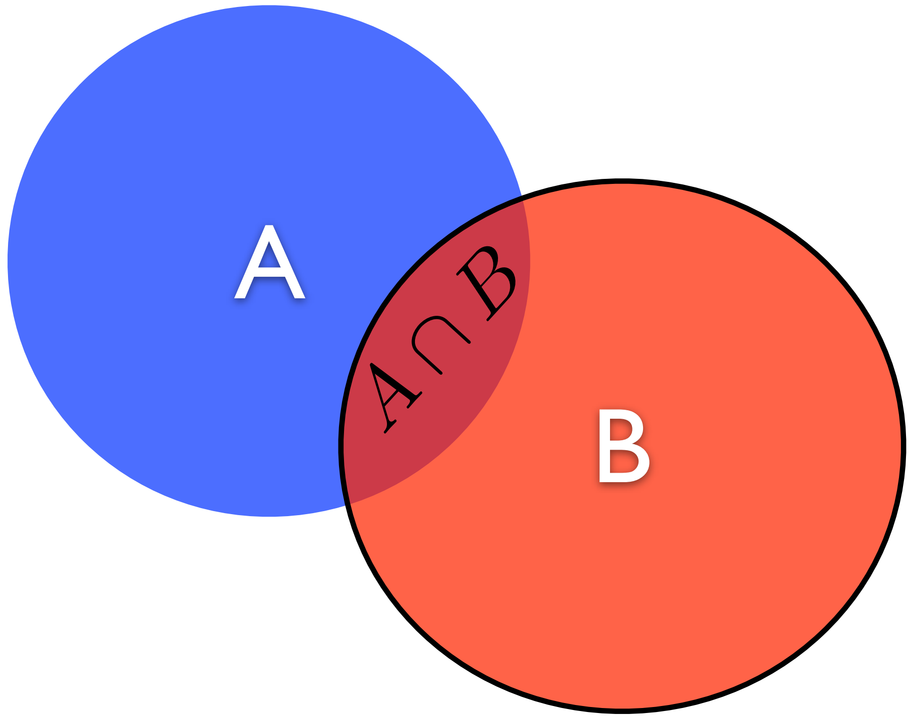
- Mapping from inputs to a finite output space
  - Contrast: *regression* and *ranking*
- Usually evaluated by *accuracy*
- Evaluated precision and recall if classes are very asymmetric in numbers or costliness (e.g., spam)
- Example: Naive Bayes
  - Simple, effective, similar to BM25
- Lots more: see book for SVM, nearest-neighbor

Axioms of Probability

- Define event space $\bigcup_i \mathcal{F}_i = \Omega$
- Probability function, s.t. $P : \mathcal{F} \rightarrow [0, 1]$
  - Disjoint events sum $A \cap B = \emptyset \Leftrightarrow P(A \cup B) = P(A) + P(B)$
  - All events sum to one $P(\Omega) = 1$
- Show that: $P(\bar{A}) = 1 - P(A)$

Conditional Probability

$$P(A \mid B) = \frac{P(A, B)}{P(B)}$$



$$P(A, B) = P(B)P(A \mid B) = P(A)P(B \mid A)$$

$$\begin{aligned} P(A_1, A_2, \ldots, A_n) &= P(A_1)P(A_2 \mid A_1)P(A_3 \mid A_1, A_2) \\ &\quad \cdots P(A_n \mid A_1, \ldots, A_{n-1}) \end{aligned}$$

Chain rule

Independence

$$
\begin{aligned}
P(A, B) &= P(A)P(B) \\
&\Leftrightarrow \\
P(A \mid B) = P(A) &\wedge P(B \mid A) = P(B)
\end{aligned}
$$

In coding terms, knowing *B* doesn't help in decoding *A*, and vice versa.

Movie Reviews

Movie Reviews

there ' s some movies i enjoy even though i know i probably shouldn ' t and have a difficult time trying to explain why i did . " lucky numbers " is a perfect example of this because it ' s such a blatant rip - off of " fargo " and every movie based on an elmore leonard novel and yet it somehow still works for me . i know i ' m in the minority here but let me explain . the film takes place in harrisburg , pa in 1988 during an unseasonably warm winter . ...

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Setting up a Classifier

Setting up a Classifier

- What we want:

  $p(☺ \mid w_1, w_2, ..., w_n) > p(☹ \mid w_1, w_2, ..., w_n)$?

Setting up a Classifier

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Setting up a Classifier

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  - A language model for each class

Setting up a Classifier

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- What we know how to build:
  - A language model for each class
    - $p(w_1, w_2, ..., w_n \mid ☺)$

Setting up a Classifier

- What we want:

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- What we know how to build:
  - A language model for each class
    - $p(w_1, w_2, \ldots, w_n \mid ☺)$
    - $p(w_1, w_2, \ldots, w_n \mid ☹)$

Bayes' Theorem

By the definition of conditional probability:

$$P(A, B) = P(B)P(A \mid B) = P(A)P(B \mid A)$$

we can show:

$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

Seemingly trivial result from 1763; interesting consequences...

Rev. T. Bayes

A “Bayesian” Classifier

$$p(R \mid w_1, w_2, \ldots, w_n) = \frac{p(R)p(w_1, w_2, \ldots, w_n \mid R)}{p(w_1, w_2, \ldots, w_n)}$$

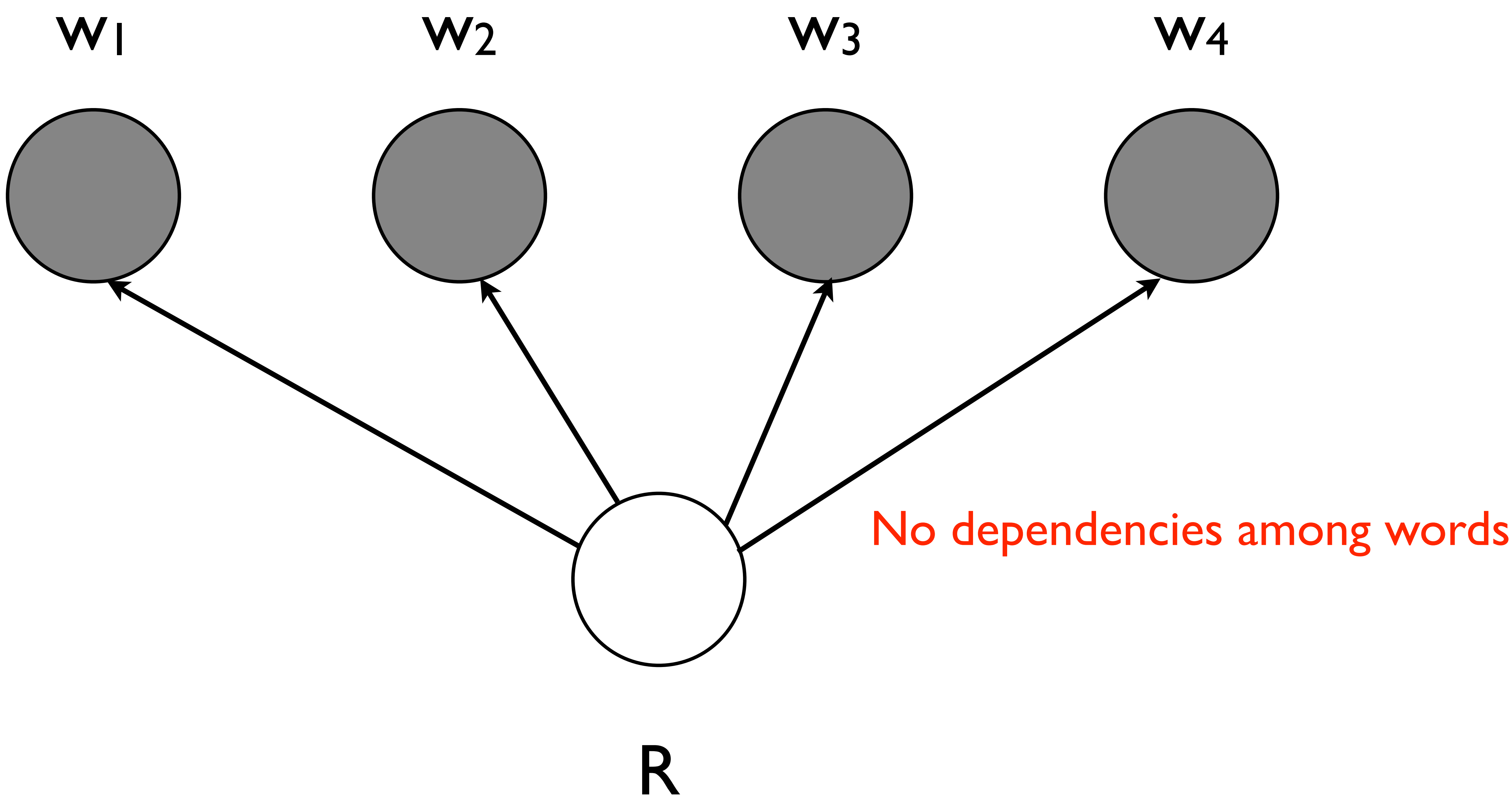
$$\max_{R \in \{\ddot{\smile}, \ddot{\frown}\}} p(R \mid w_1, w_2, \ldots, w_n) = \max_{R \in \{\ddot{\smile}, \ddot{\frown}\}} p(R)p(w_1, w_2, \ldots, w_n \mid R)$$

Posterior

Prior

Likelihood

Naive Bayes Classifier



NB on Movie Reviews

- Train models for positive, negative
- For each review, find higher posterior
- Which word probability ratios are highest?

```
>>> classifier.show_most_informative_features(5)

classifier.show_most_informative_features(5)
Most Informative Features
   contains(outstanding) = True              pos : neg    =     14.1 : 1.0
         contains(mulan) = True              pos : neg    =      8.3 : 1.0
        contains(seagal) = True              neg : pos    =      7.8 : 1.0
   contains(wonderfully) = True              pos : neg    =      6.6 : 1.0
         contains(damon) = True              pos : neg    =      6.1 : 1.0
```

What's Wrong With NB?

- What happens for word dependencies are strong?
- What happens when some words occur only once?
- What happens when the classifier sees a new word?

ML for Naive Bayes

- Recall: p(+ | Damon movie)

  = p(Damon | +) p(movie | +) p(+)

- If corpus of positive reviews has 1000 words, and "Damon" occurs 50 times,

  p_{ML}(Damon | +) = ?

- If pos. corpus has "Affleck" 0 times,

  p(+ | Affleck Damon movie) = ?

Will the Sun Rise Tomorrow?

Will the Sun Rise Tomorrow?

Laplace's Rule of Succession:
On day n+1, we've observed that the sun has risen s times before.

$$p_{Lap}(S_{n+1} = 1 \mid S_1 + \cdots + S_n = s) = \frac{s+1}{n+2}$$

What's the probability on day 0?
On day 1?
On day 10^6?
Start with prior assumption of equal rise/not-rise probabilities; *update* after every observation.

SpamAssassin Features

- Basic (Naïve) Bayes spam probability
- Mentions: Generic Viagra
- Regex: millions of (dollar) ((dollar) NN,NNN,NNN.NN)
- Phrase: impress ... girl
- Phrase: 'Prestigious Non-Accredited Universities'
- From: starts with many numbers
- Subject is all capitals
- HTML has a low ratio of text to image area
- Relay in RBL, http://www.mail-abuse.com/enduserinfo_rbl.html
- RCVD line looks faked
- http://spamassassin.apache.org/tests_3_3_x.html

Naive Bayes is Not So Naive

- Very fast learning and testing (basically just count words)
- Low storage requirements
- Very good in domains with many <u>equally important</u> features
- More robust to irrelevant features than many learning methods

  Irrelevant features cancel each other without affecting results

Naive Bayes is Not So Naive

- More robust to concept drift (changing class definition over time)
- Naive Bayes won 1st and 2nd place in KDD-CUP 97 competition out of 16 systems

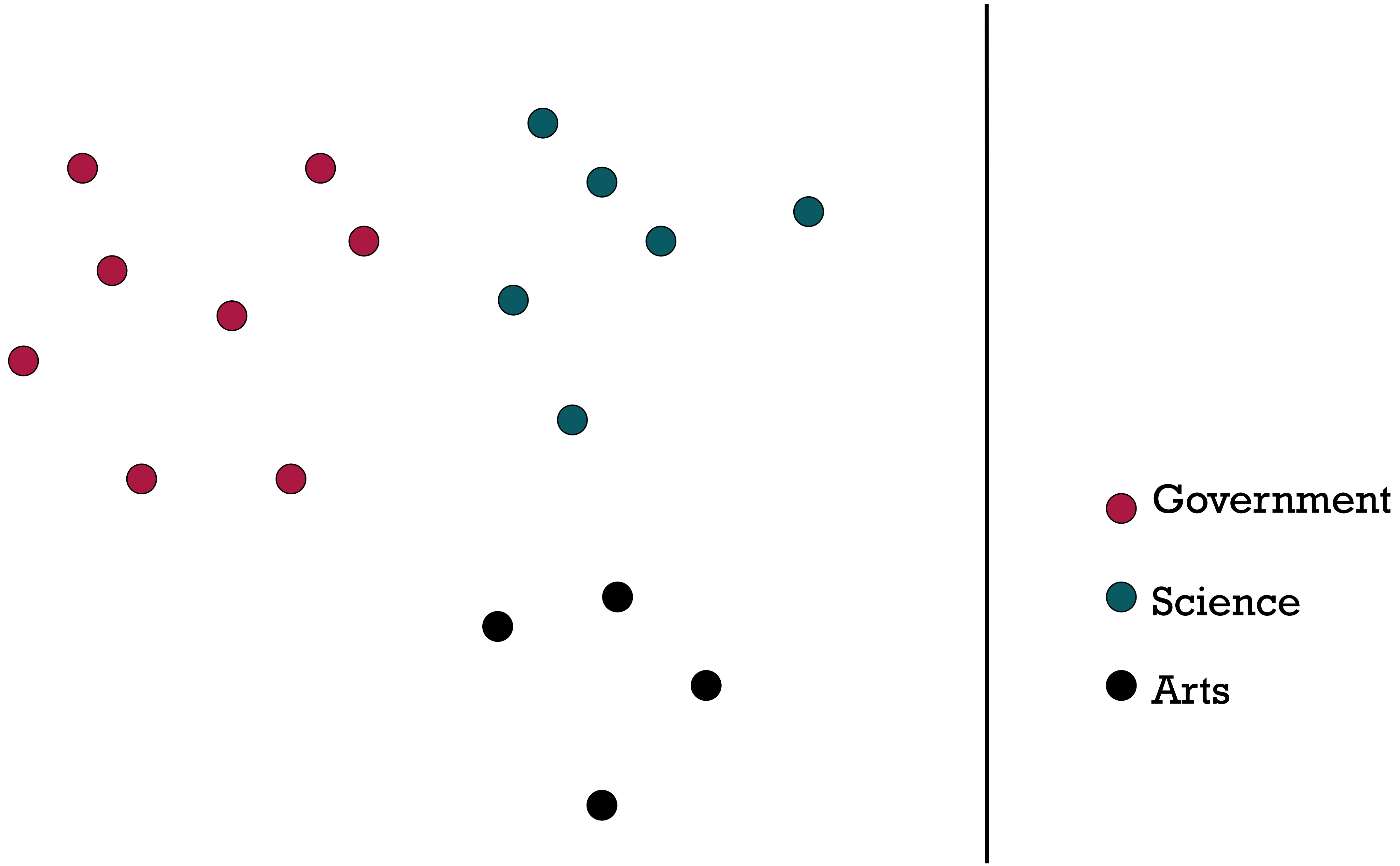
  Goal: Financial services industry direct mail response prediction: Predict if the recipient of mail will actually respond to the advertisement – 750,000 records.

- A good dependable baseline for text classification (but not the best)!

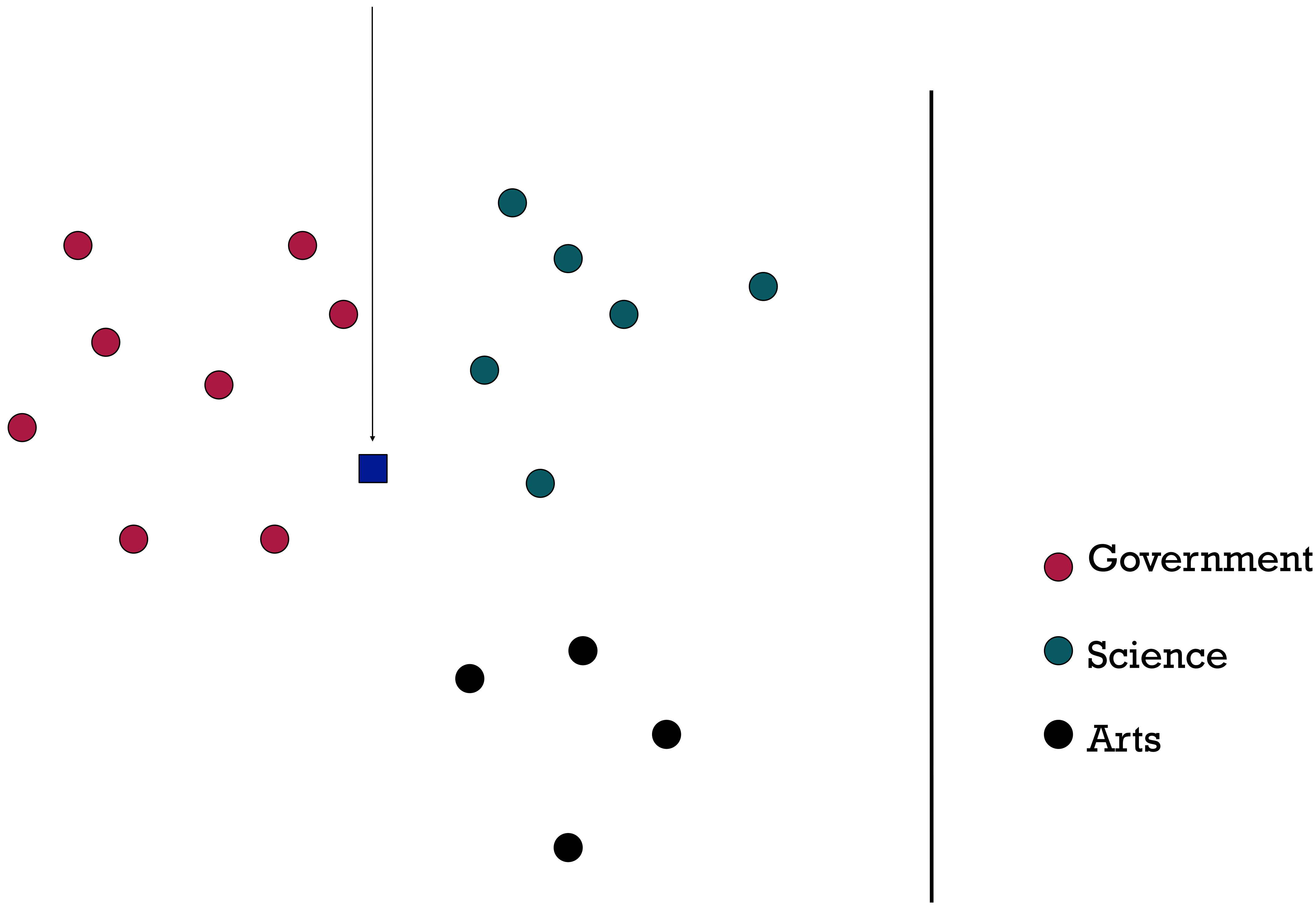
Classification Using Vector Spaces

- In vector space classification, training set corresponds to a labeled set of points (equivalently, vectors)
- Premise 1: Documents in the same class form a contiguous region of space
- Premise 2: Documents from different classes don't overlap (much)
- Learning a classifier: build surfaces to delineate classes in the space

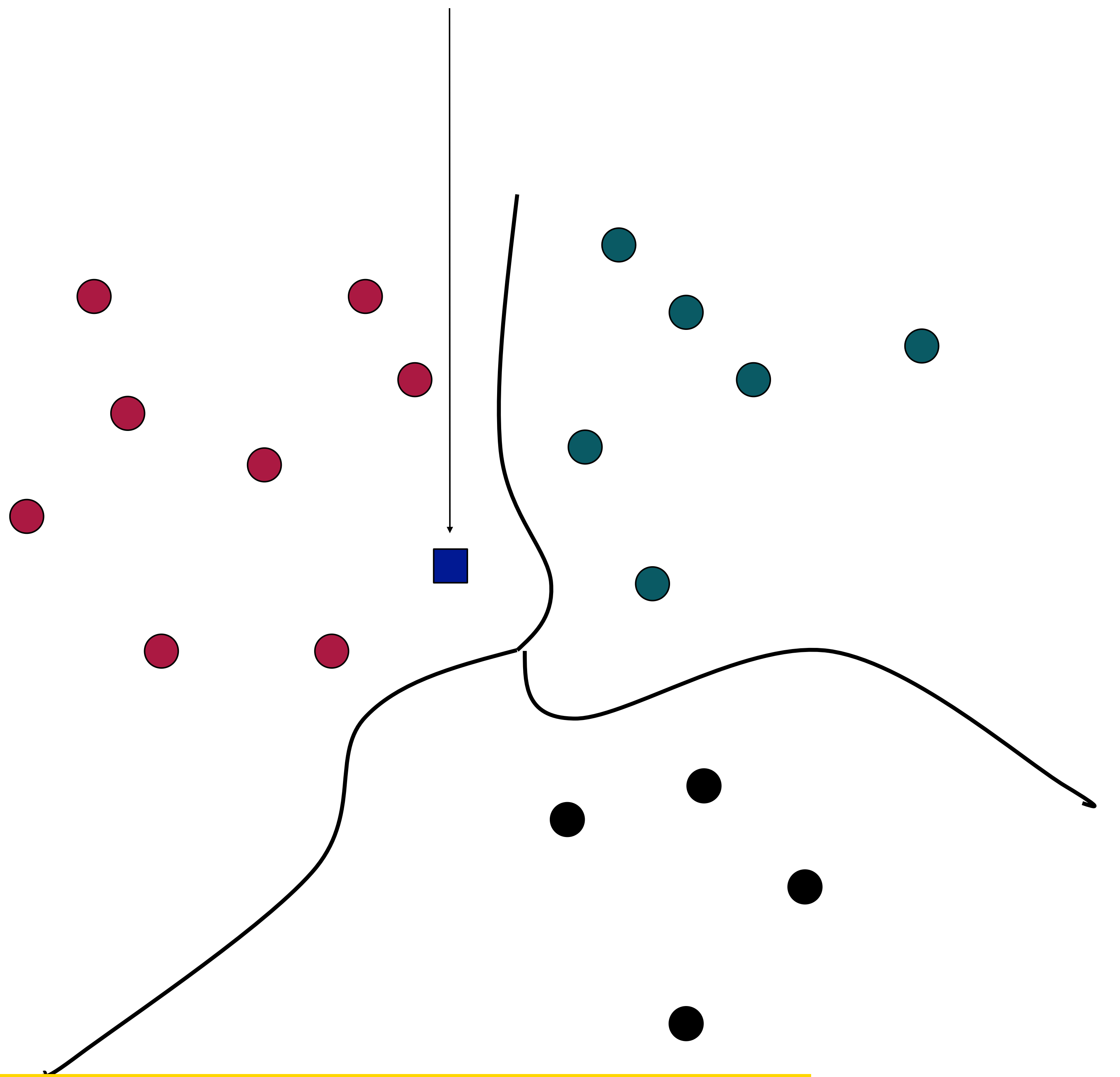
Documents in a Vector Space



Test Document of what class?



Test Document = Government



Is this similarity hypothesis true in general?

Government

Science

Arts

Our focus: how to find good separators

Definition of centroid

$$\vec{\mu}(c) = \frac{1}{|D_c|}$$

- Where D_c is the set of all documents that belong to class c and $v(d)$ is the vector space representation of *d.*

- *Note that centroid will in general* not *be a unit vector even when the inputs are unit vectors.*

Rocchio classification

- Rocchio forms a simple representative for each class: the centroid/prototype
- Classification: nearest prototype/centroid
- It does not guarantee that classifications are consistent with the given training data
- Remember: Used with two classes for relevance feedback

Rocchio classification

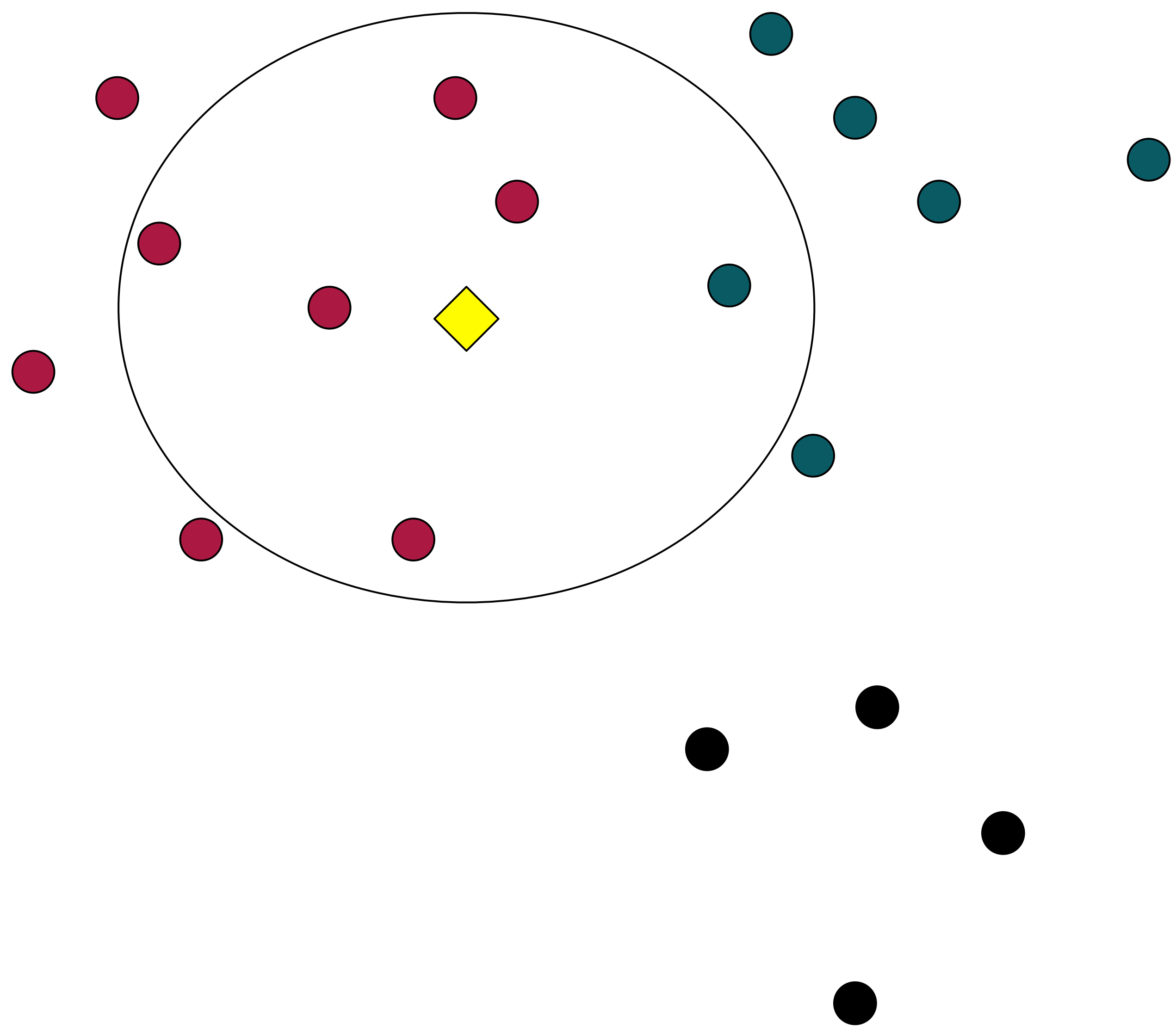
- Little used outside text classification
  - It has been used quite effectively for text classification
  - But in general worse than Naïve Bayes
- Again, cheap to train and test documents

k Nearest Neighbor Classification

- kNN = *k* Nearest Neighbor

- To classify a document *d*:
- Define *k*-neighborhood as the *k* nearest neighbors of *d*
- Pick the majority class label in the *k*-neighborhood

Example: k=6 (6NN)



P(science|◇)?

Government

Science

Arts

Nearest-Neighbor Learning

Nearest-Neighbor Learning

- Learning: just store the labeled training examples *D*
- Testing instance *x (under 1NN)*:
  - Compute similarity between *x* and all examples in *D*.
  - Assign *x* the category of the most similar example in *D*.
- Does not compute anything beyond storing the examples

Nearest-Neighbor Learning

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- Also called:
  - Case-based learning
  - Memory-based learning
  - Lazy learning

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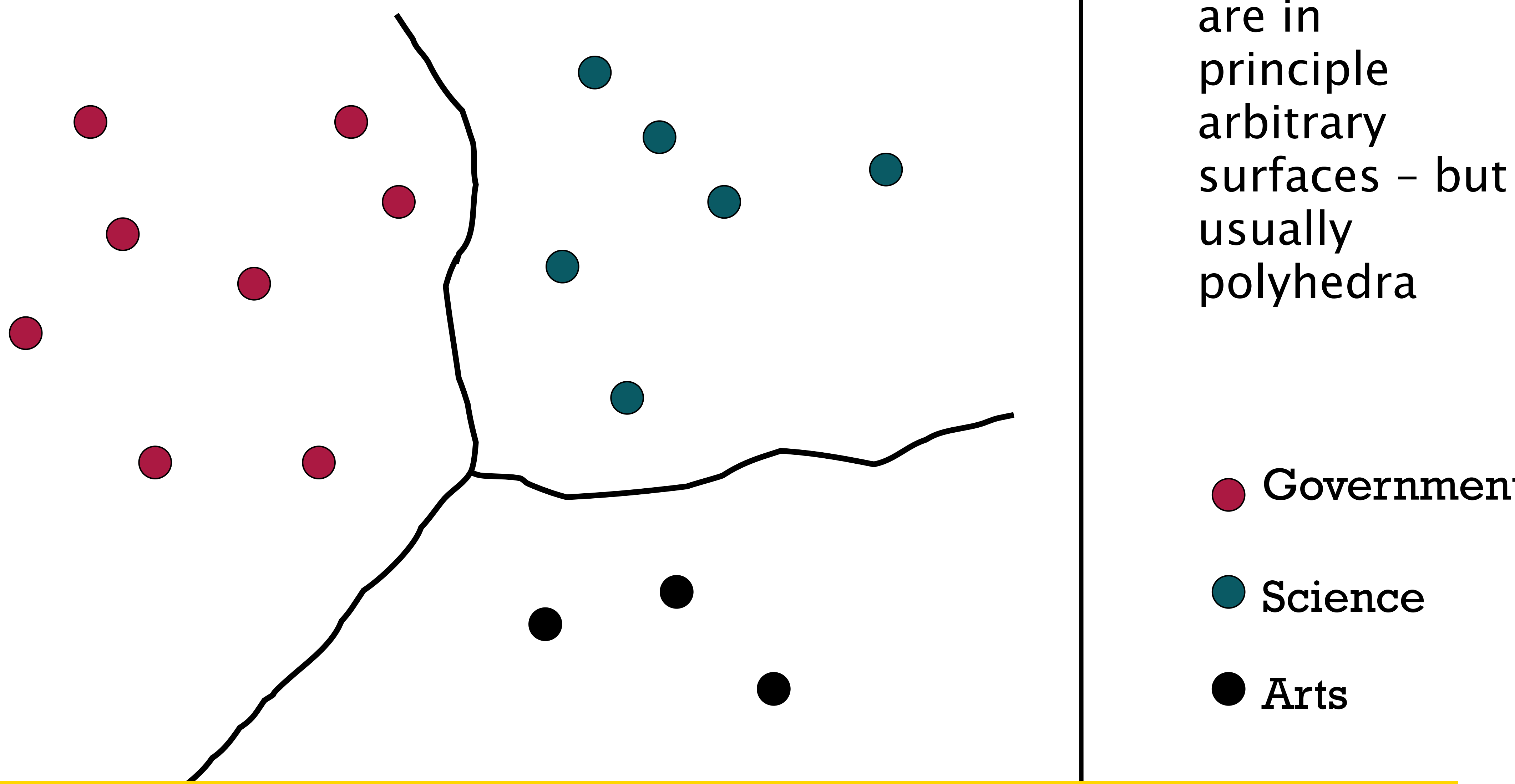
  - Case-based learning
  - Memory-based learning
  - Lazy learning
- Rationale of kNN: contiguity hypothesis

k Nearest Neighbor

- Using only the closest example (1NN) subject to errors due to:
  - A single atypical example.
  - Noise (i.e., an error) in the category label of a single training example.
- More robust: find the *k* examples and return the majority category of these *k*
- *k* is typically odd to avoid ties; 3 and 5 are most common

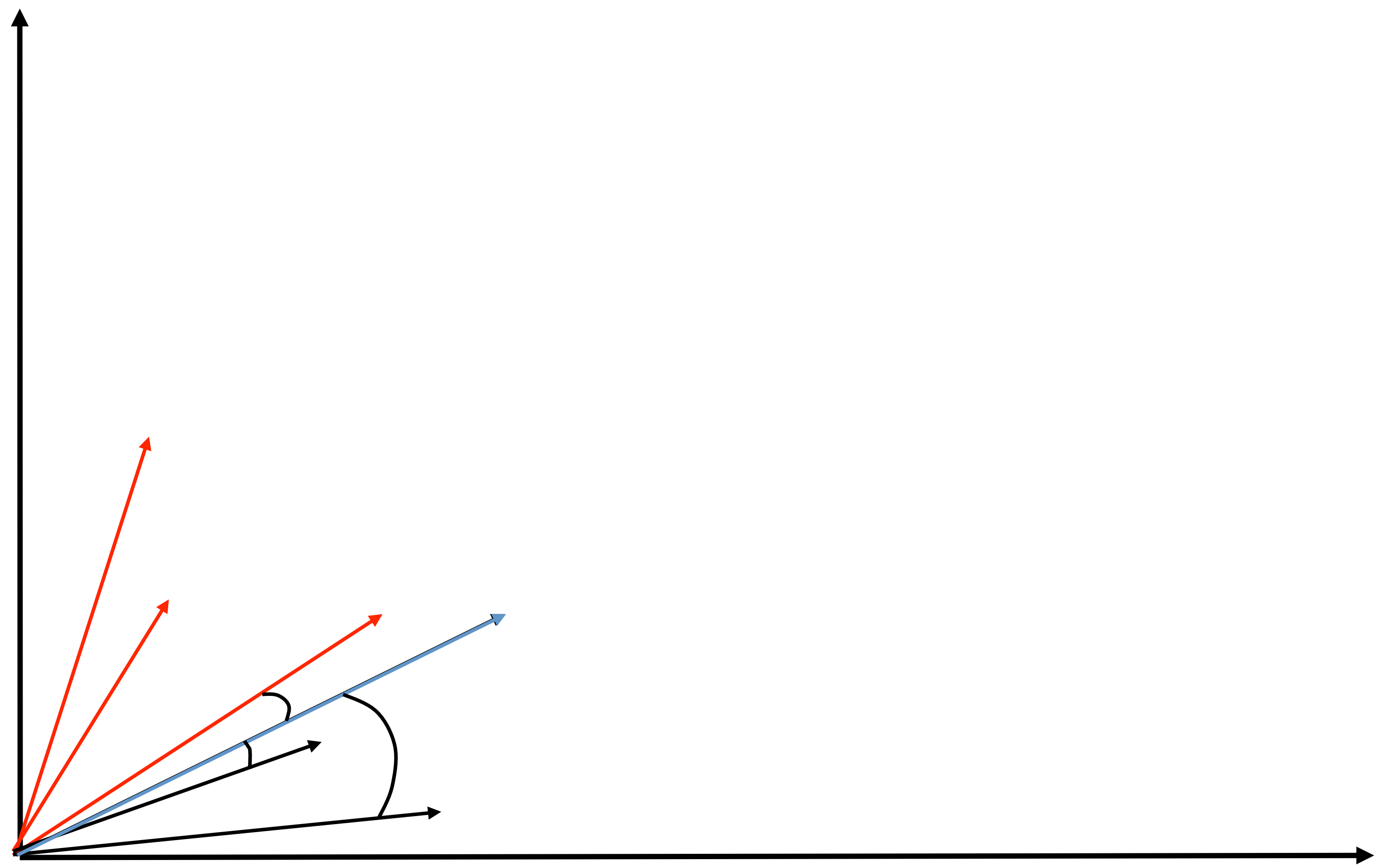
kNN decision boundaries



Boundaries are in principle arbitrary surfaces – but usually polyhedra

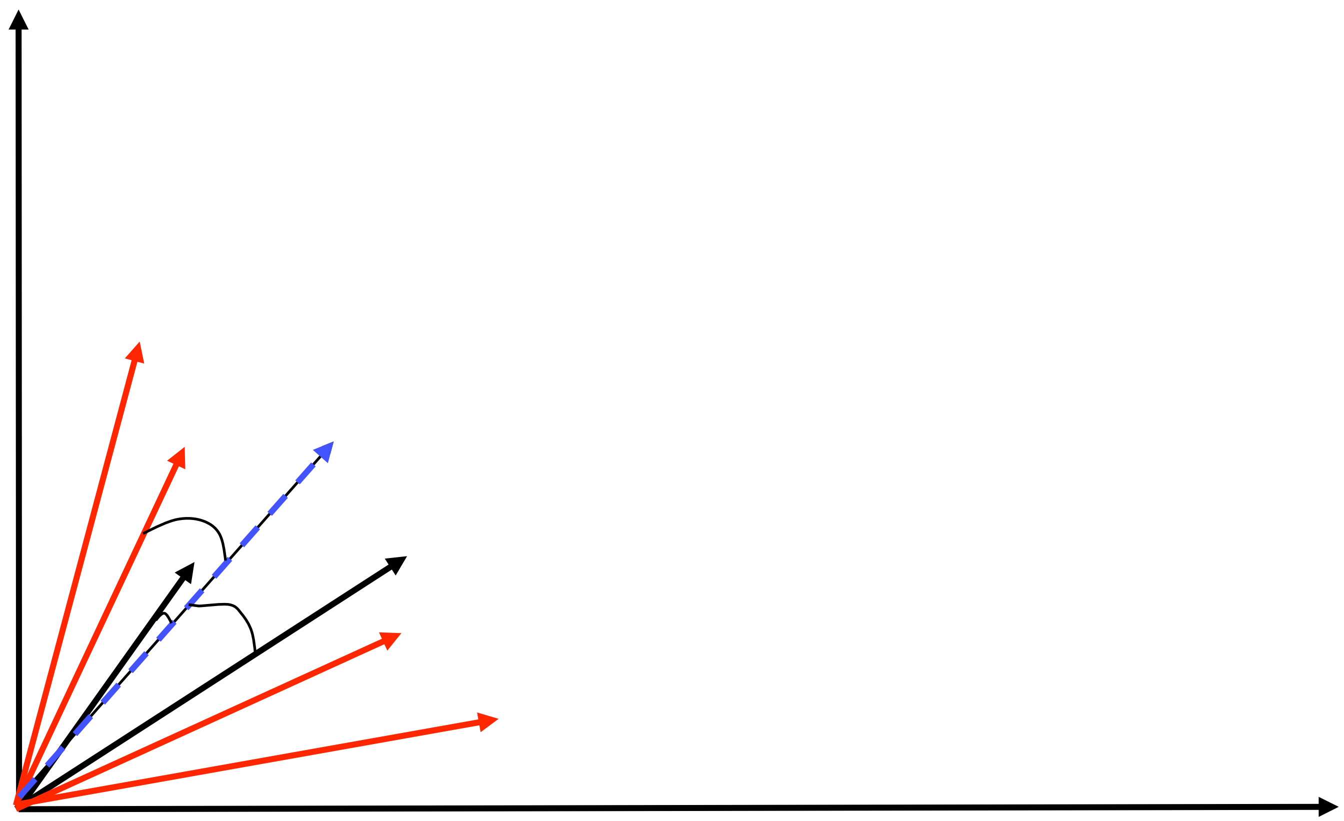
kNN gives locally defined decision boundaries between classes – far away points do not influence each classification decision (unlike in Naïve Bayes, Rocchio, etc.)

Illustration of 3 Nearest Neighbor for Text Vector Space



3 Nearest Neighbor vs. Rocchio

- Nearest Neighbor tends to handle polymorphic categories better than Rocchio/NB.



kNN: Discussion

- No feature selection necessary
- No training necessary
- Scales well with large number of classes
  - Don't need to train *n* classifiers for *n* classes
- Classes can influence each other
  - Small changes to one class can have ripple effect
- May be expensive at test time
- In most cases it's more accurate than NB or Rocchio

Let's test our intuition

- Can a bag of words always be viewed as a vector space?
- What about a bag of features?
- Can we always view a standing query as a region in a vector space?
- What about Boolean queries on terms?
- What do "rectangles" equate to?

Bias vs. capacity – notions and terminology

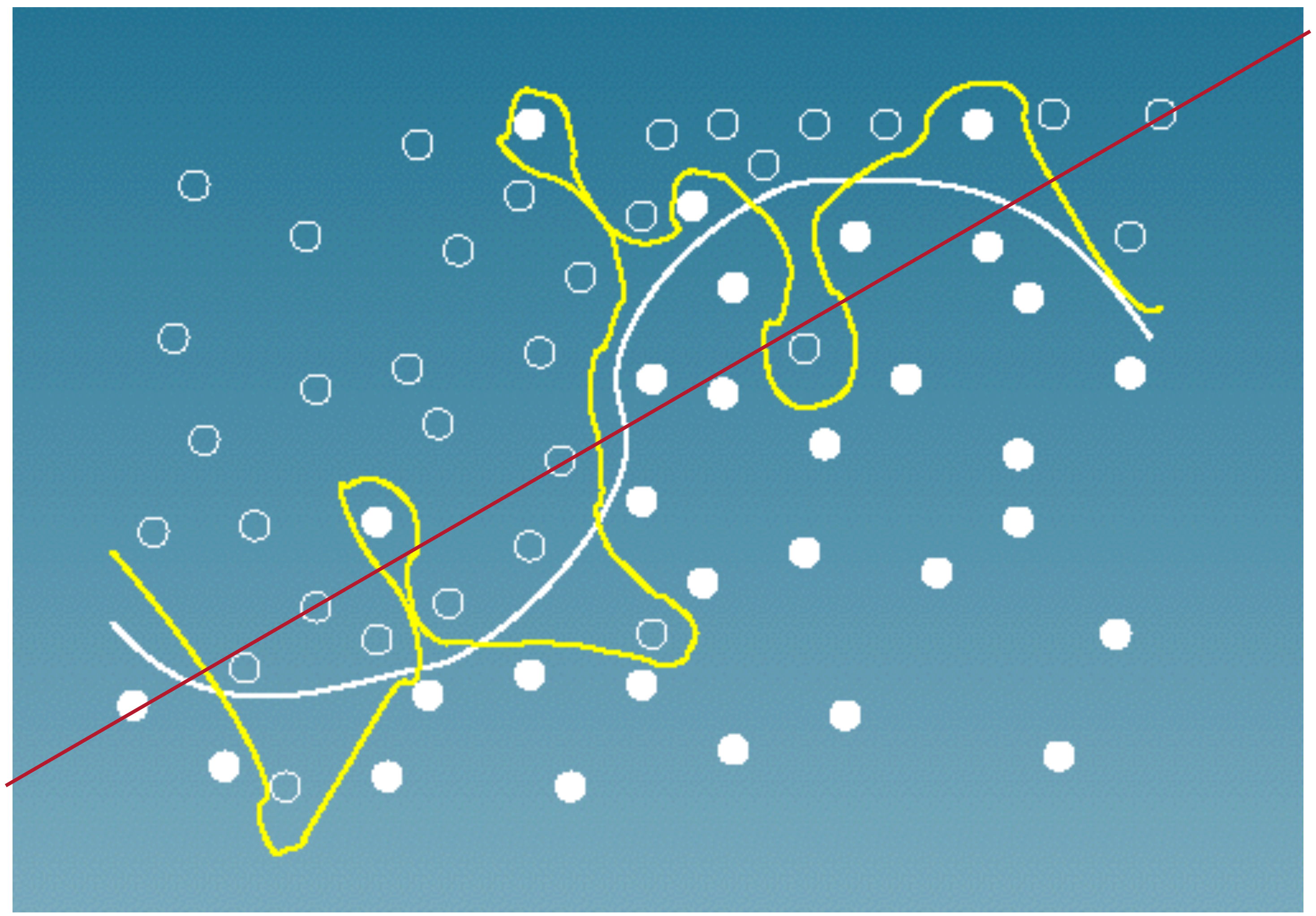
- Consider asking a botanist: Is an object a tree?
  - Too much *capacity*, low *bias*
    - Botanist who memorizes
    - Will always say "no" to new object (e.g., different # of leaves)
  - Not enough capacity, high bias
    - Lazy botanist
    - Says "yes" if the object is green
  - You want the middle ground

(Example due to C. Burges)

kNN vs. Naive Bayes

- Bias/Variance tradeoff
  - Variance ≈ Capacity
- kNN has high variance and low bias.
  - Infinite memory
- NB has low variance and high bias.
  - Linear decision surface (hyperplane – see later)

Bias vs. variance: Choosing the correct model capacity



Summary: Representation of Text Categorization Attributes

- Representations of text are usually very high dimensional
- High-bias algorithms that prevent overfitting should generally work best in high-dimensional space
- For most text categorization tasks, there are many relevant features and many irrelevant ones

Which classifier do I use for a given text classification problem?

- Is there a learning method that is optimal for all text classification problems?
- No, because there is a tradeoff between bias and variance.
- Factors to take into account:
  - How much training data is available?
  - How simple/complex is the problem? (linear vs. nonlinear decision boundary)
  - How noisy is the data?
  - How stable is the problem over time?
    - For an unstable problem, its better to use a simple and robust classifier.

Clustering

Clustering

- Unsupervised structure discovery
- Exploratory data analysis
- Clustering for word senses
- Clustering for retrieval effectiveness
  - Some have also proposed clustering for efficiency

A Concordance for "party"

- thing. She was talking at a party thrown at Daphne's restaurant in
- have turned it into the hot dinner-party topic. The comedy is the
- selection for the World Cup party, which will be announced on May 1
- in the 1983 general election for a party which, when it could not bear to
- to attack the Scottish National Party, who look set to seize Perth and
- that had been passed to a second party who made a financial decision
- the by-pass there will be a street party. "Then," he says, "we are going
- number-crunchers within the Labour party, there now seems little doubt
- political tradition and the same party. They are both relatively Anglophilic
- he told Tony Blair's modernised party they must not retreat into "warm
- "Oh no, I'm just here for the party," they said. "I think it's terrible
- A future obliges each party to the contract to fulfil it by
- be signed by or on behalf of each party to the contract." Mr David N

What Good are Word Senses?

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What Good are Word Senses?

- John threw a "rain forest" party last December. His living room was full of plants and his box was playing Brazilian music …

What Good are Word Senses?

- Replace word w with sense s
  - Splits w into senses: distinguishes this token of w from tokens with sense t
  - Groups w with other words: groups this token of w with tokens of x that also have sense s

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  - Axioms about TRANSFER apply to (some tokens of) `throw`
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- Backoff for just about anything
  - what word comes next? (speech recognition, language ID, …)
    - trigrams are sparse but tri-meanings might not be
  - bilexical PCFGs: p(S[`devour`] → NP[`lion`] VP[`devour`] | S[`devour`])
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    - approximate by p(S[EAT] → NP[`lion`] VP[EAT] | S[EAT])
- Speaker's real intention is senses; words are a noisy channel

Cues to Word Sense

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- Adjacent words (or their senses)

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- Adjacent words (or their senses)
- Grammatically related words (subject, object, …)
- Other nearby words
- Topic of document
- Sense of other tokens of the word in the same document

Words as Vectors

- Represent each word **type** w by a point in k-dimensional space
  - e.g., k is size of vocabulary
  - the 17^{th} coordinate of w represents **strength** of w's association with vocabulary word 17

Words as Vectors

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From corpus:

Arlen Specter **abandoned** the Republican **party**.
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The **party** **above** the art gallery was, **above** all, a laboratory for synthesizing **zygotes** and beer.

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- should correct for commonness of word (e.g., "above")

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- Plot all word types in k-dimensional space
- Look for **clusters** of close-together types

Learning Classes by Clustering

- Plot all word types in k-dimensional space
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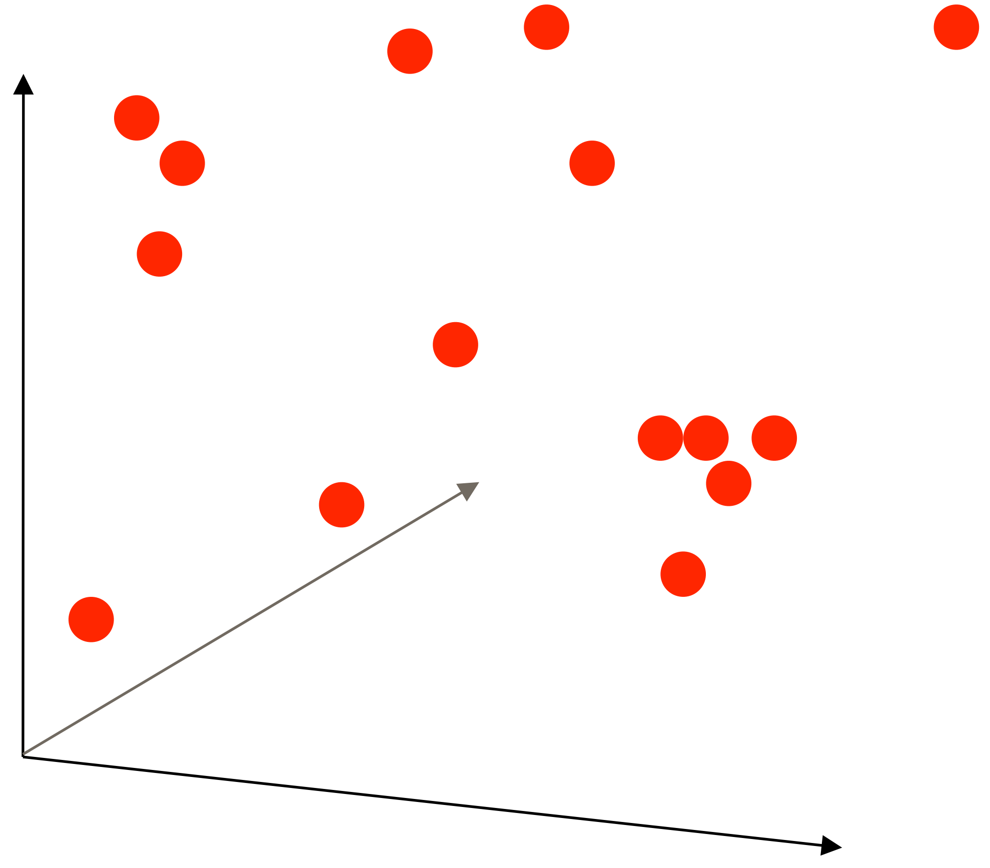
Plot in k dimensions (here k=3)



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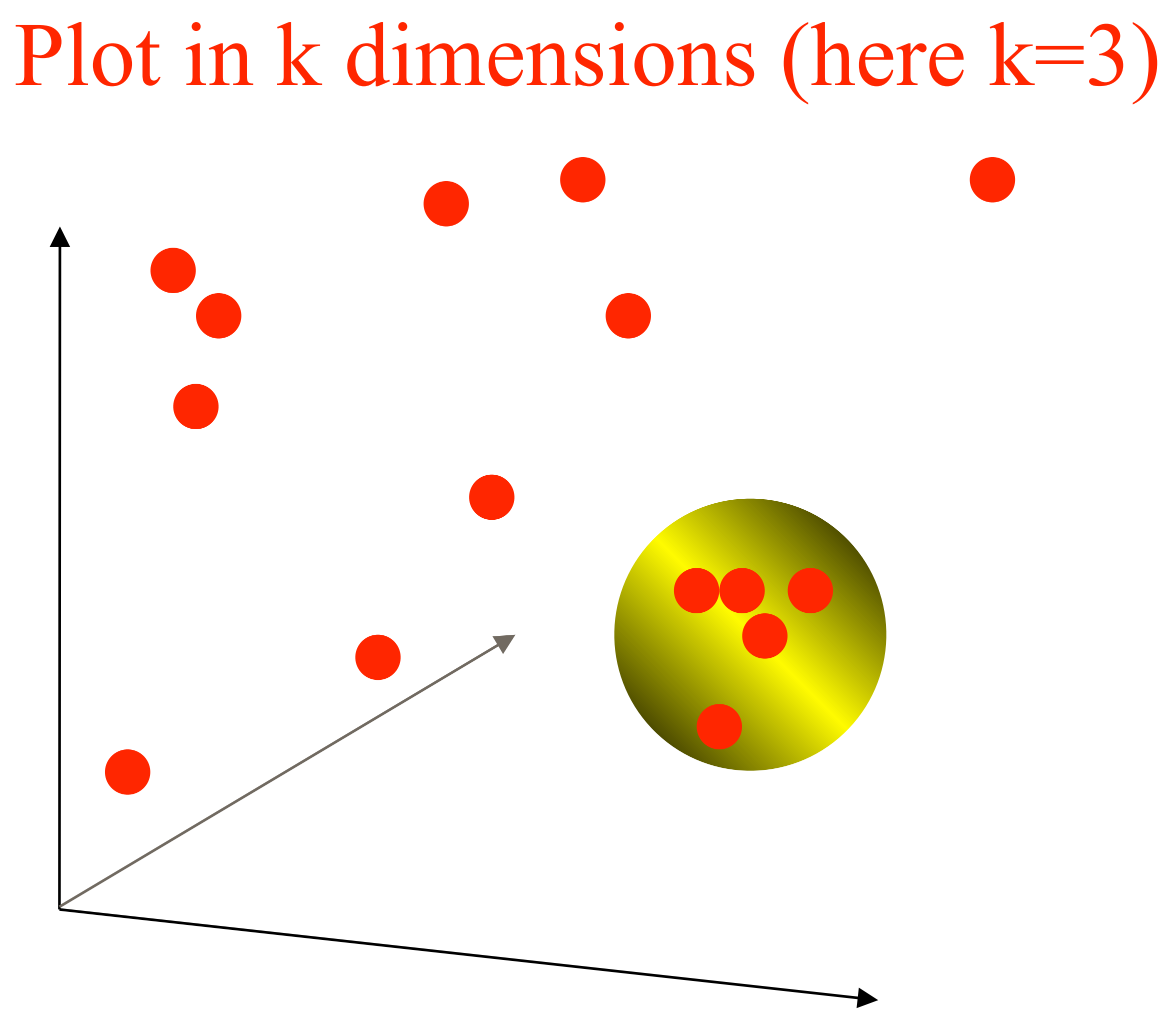

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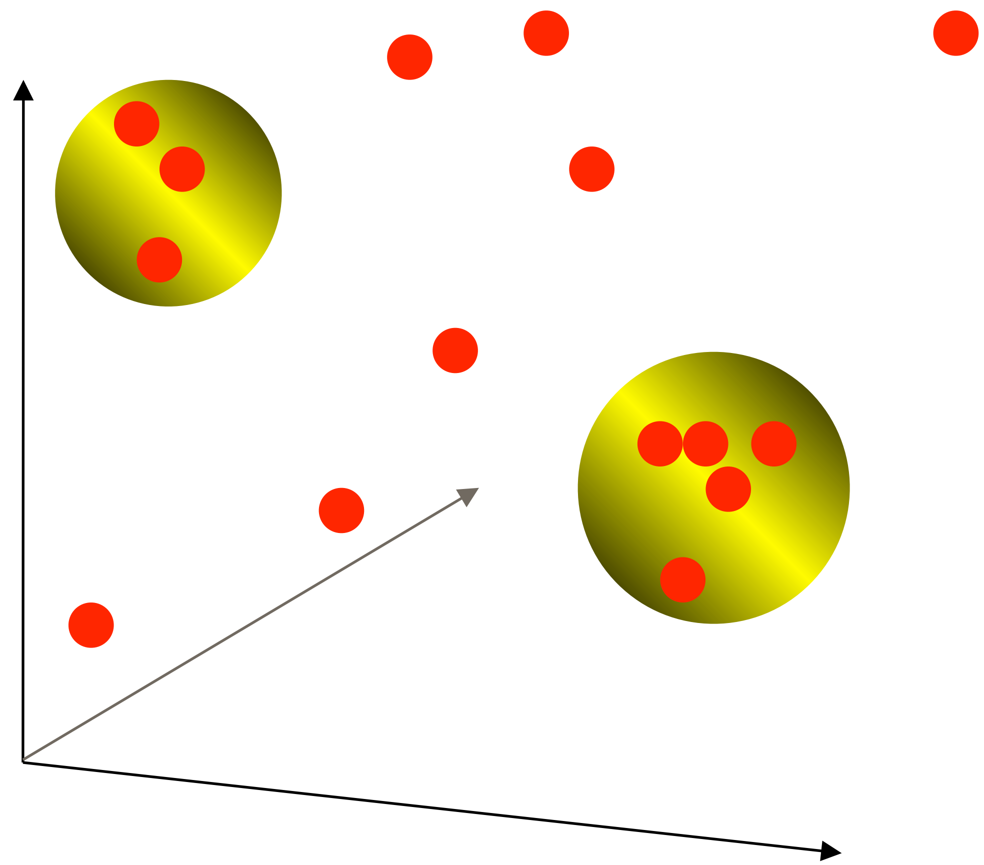
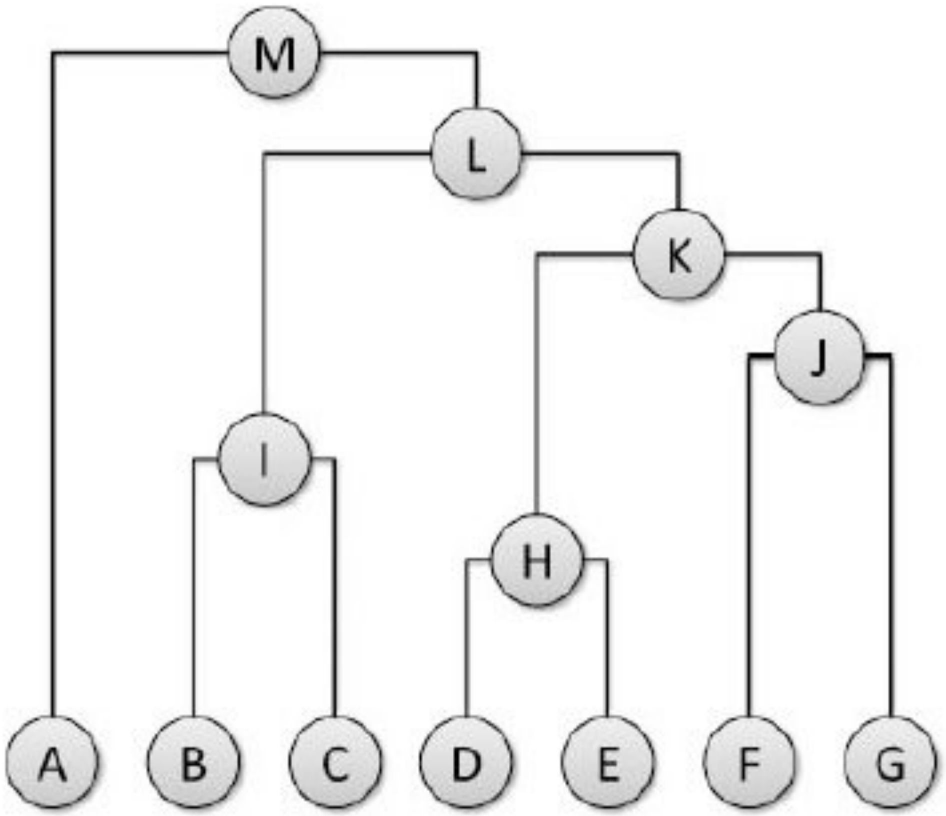


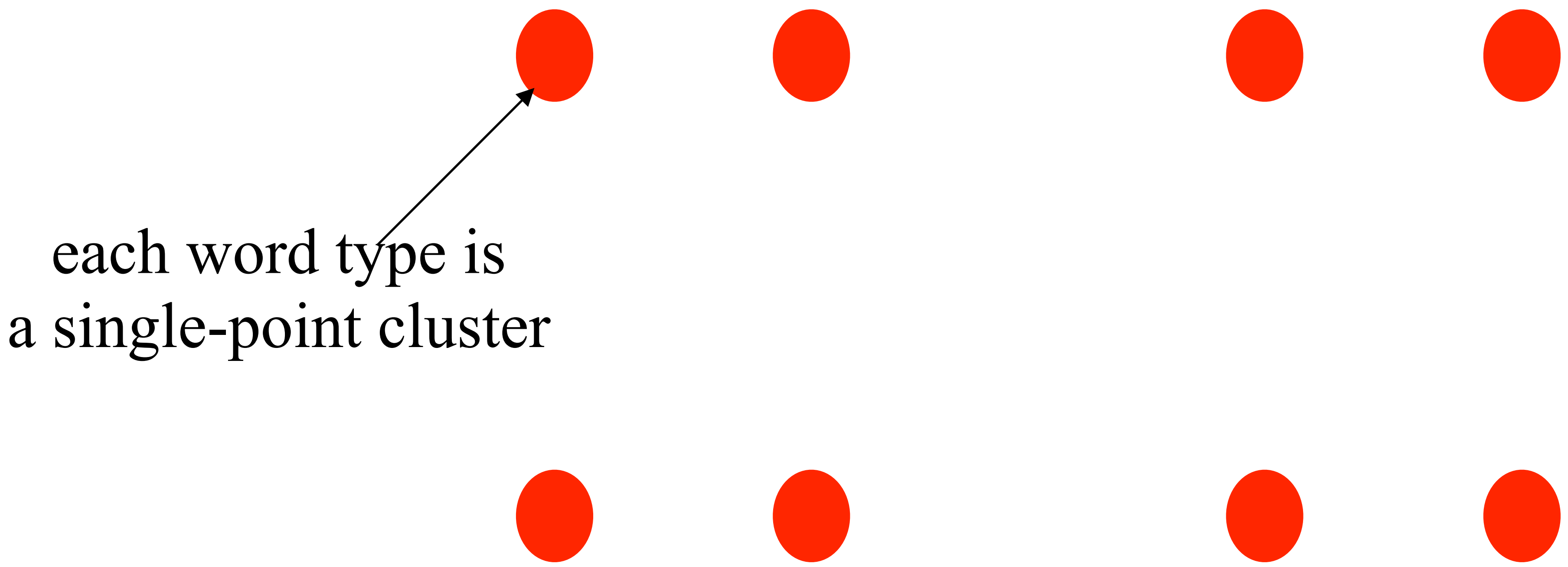
Bottom-Up Clustering

- Start with one cluster per point
- Repeatedly merge 2 closest clusters
  - Single-link: dist(A,B) = min dist(a,b) for $a \in A$, $b \in B$
  - Complete-link: dist(A,B) = max dist(a,b) for $a \in A$, $b \in B$
- Produces a dendrogram



example from Manning & Schütze

Bottom-Up Clustering – Single-Link



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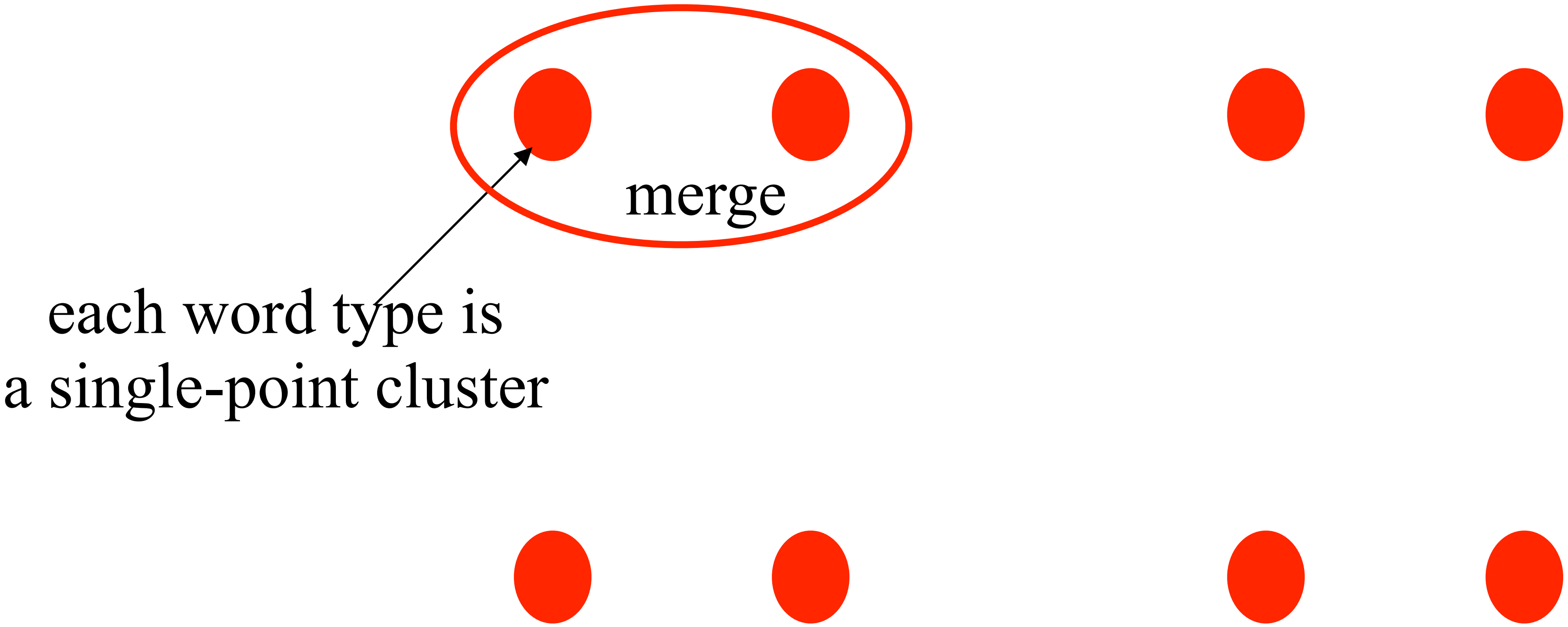

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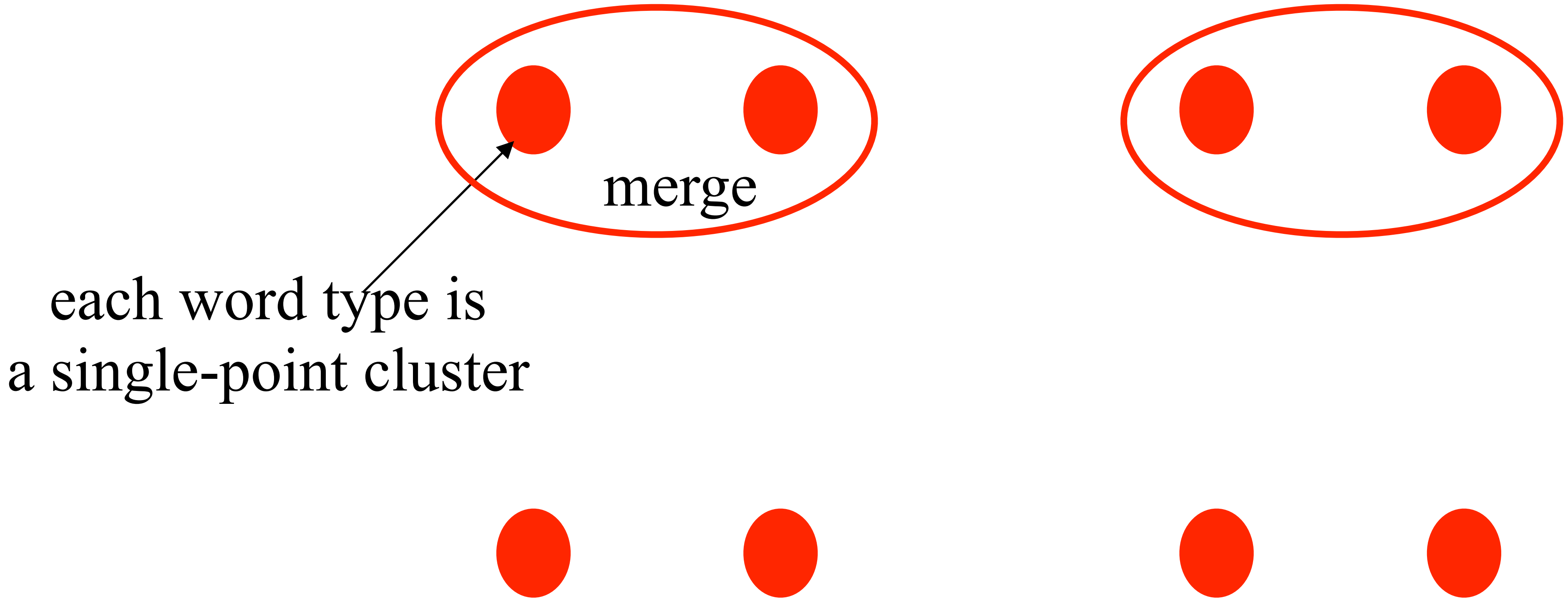

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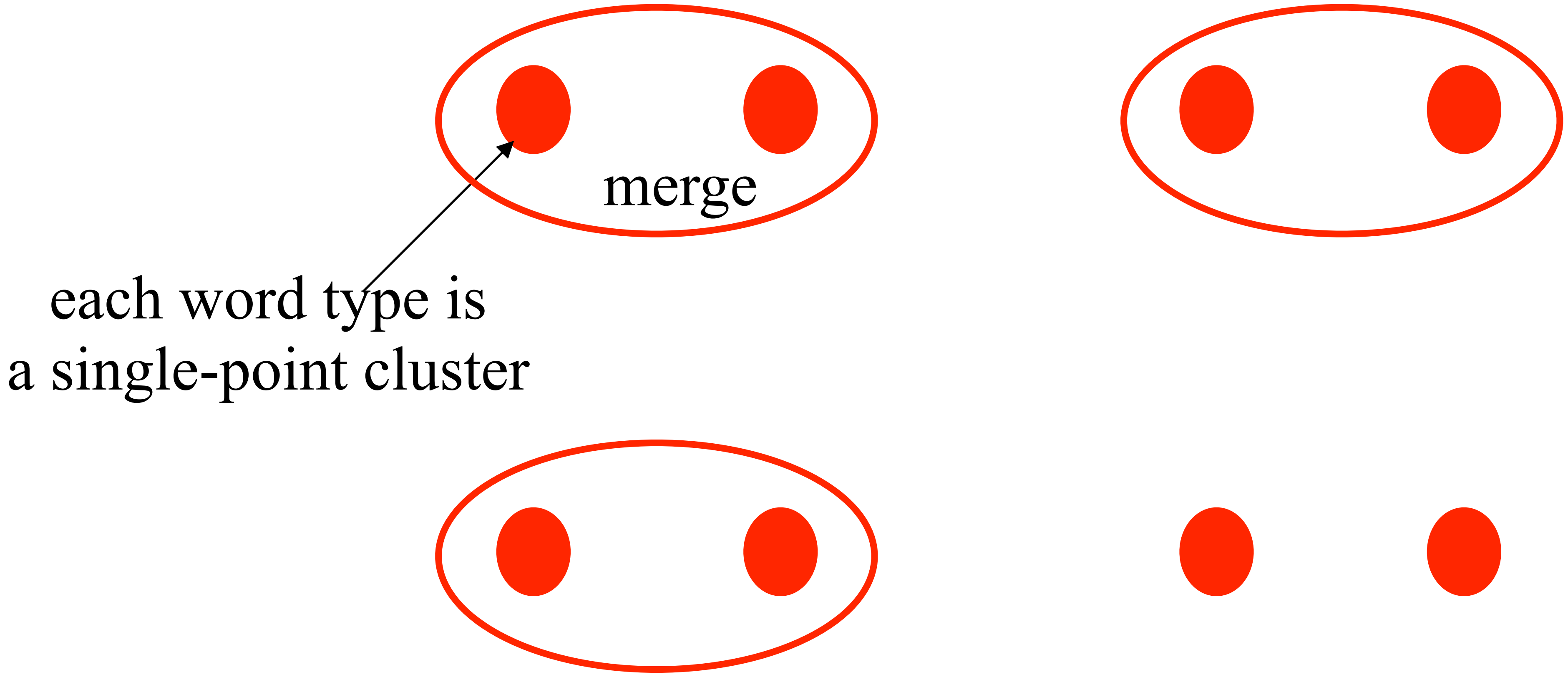

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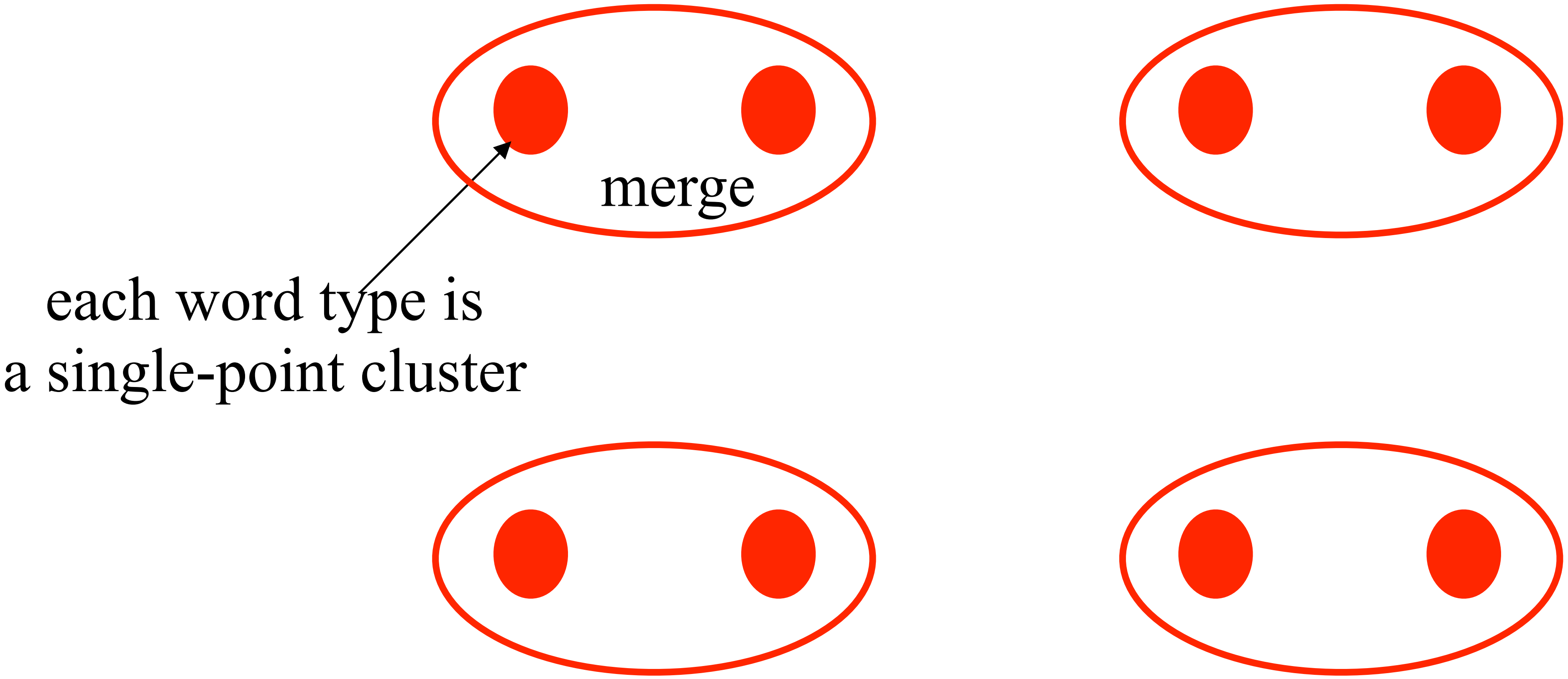

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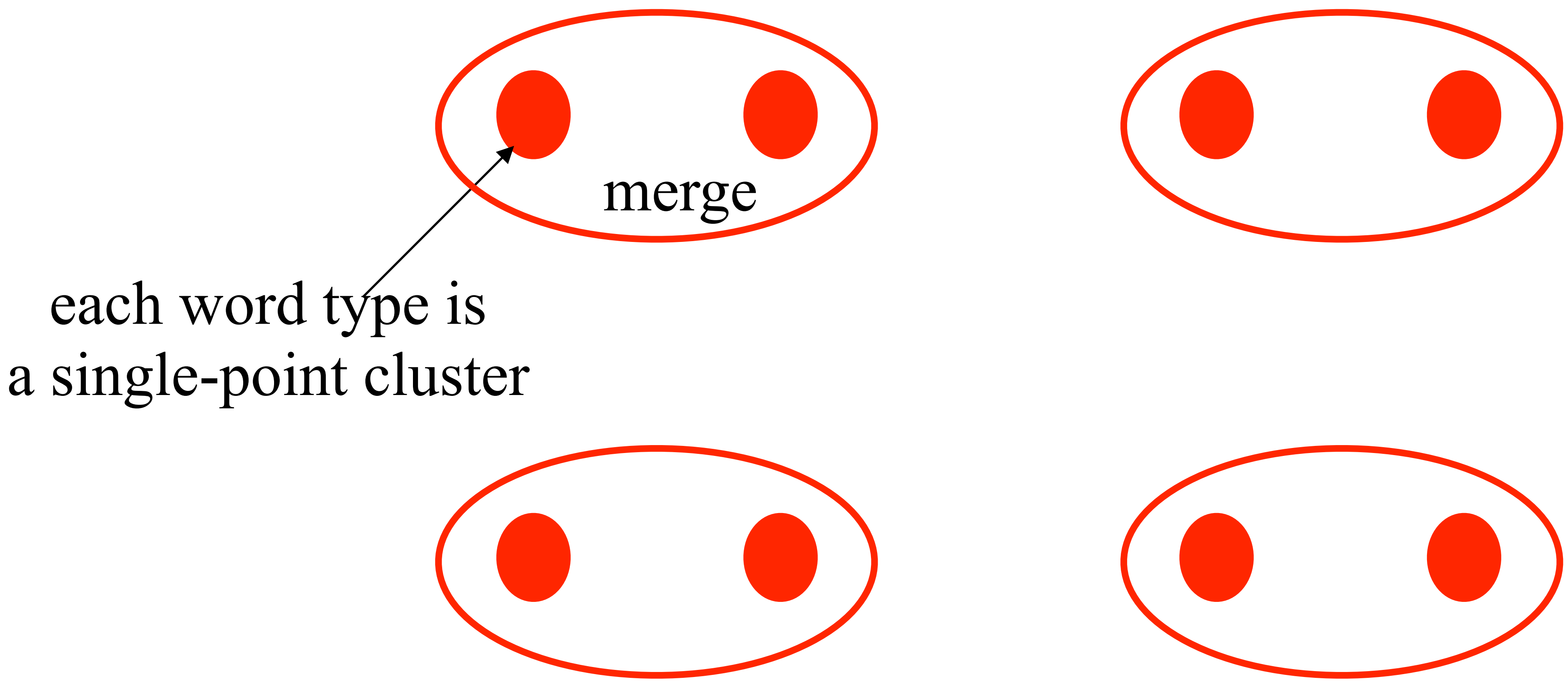
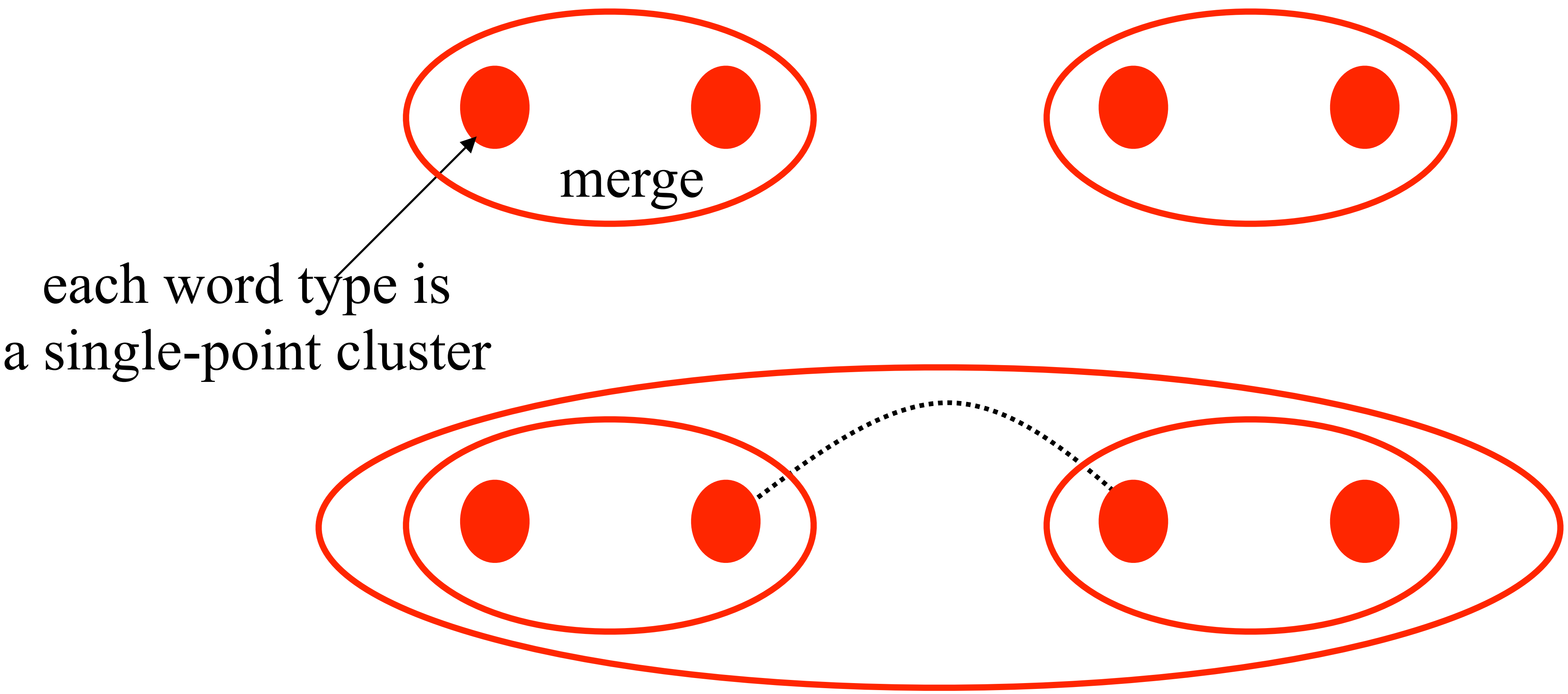


Again, merge closest pair of clusters:

Single-link: clusters are close if any of their points are

$\text{dist}(A,B) = \min \text{dist}(a,b)$ for $a \in A$, $b \in B$

Bottom-Up Clustering – Single-Link



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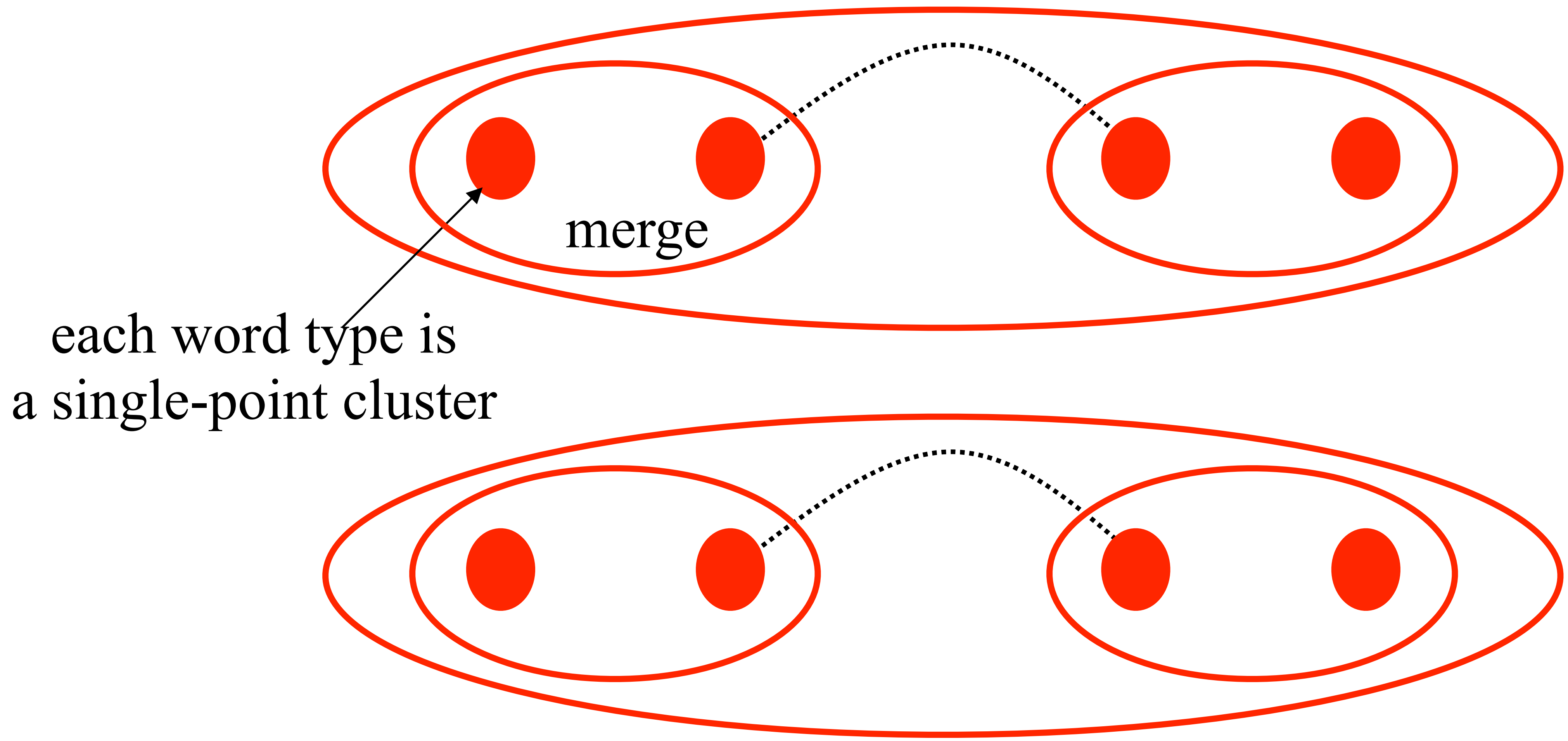

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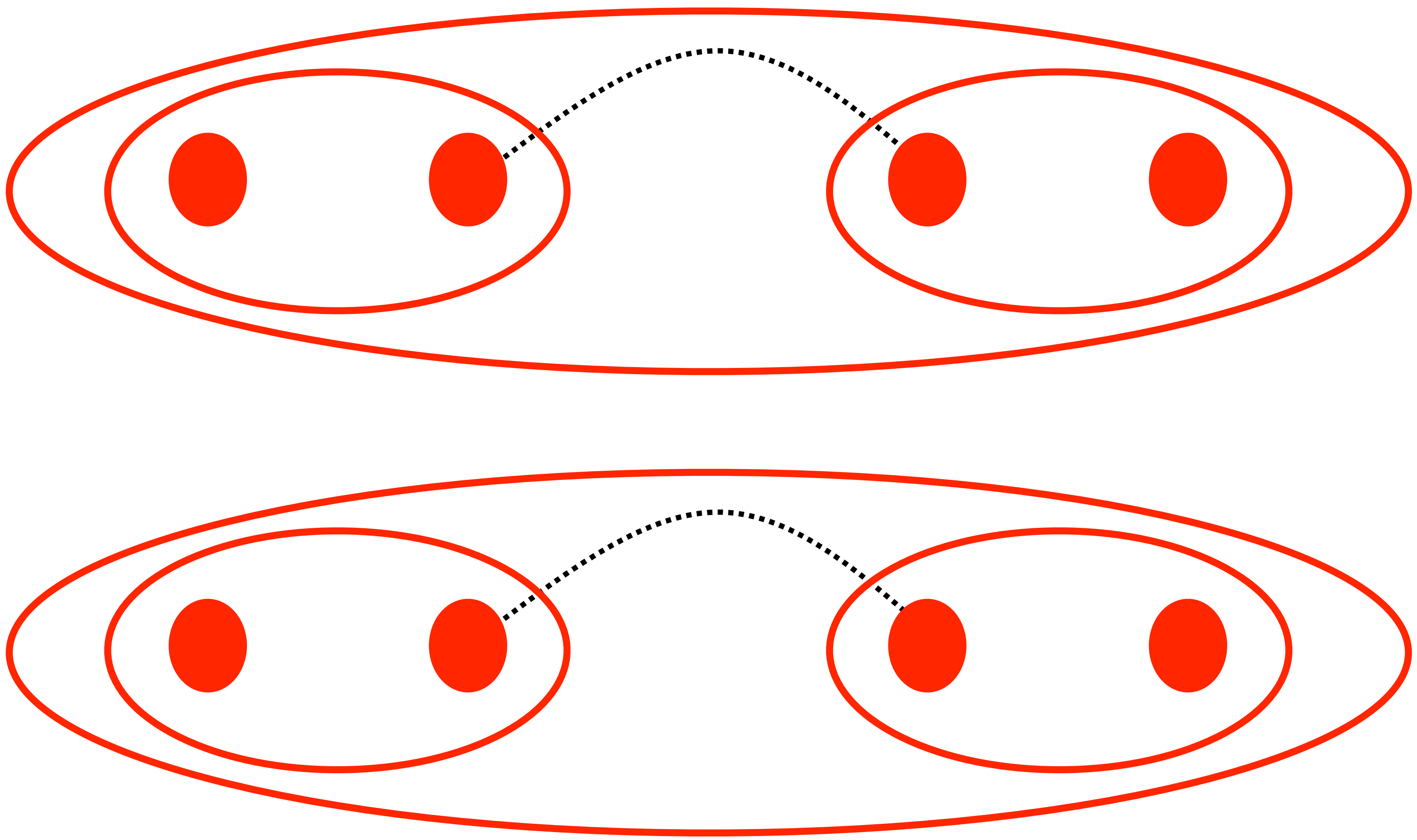

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Fast, but tend to get long, stringy, meandering clusters

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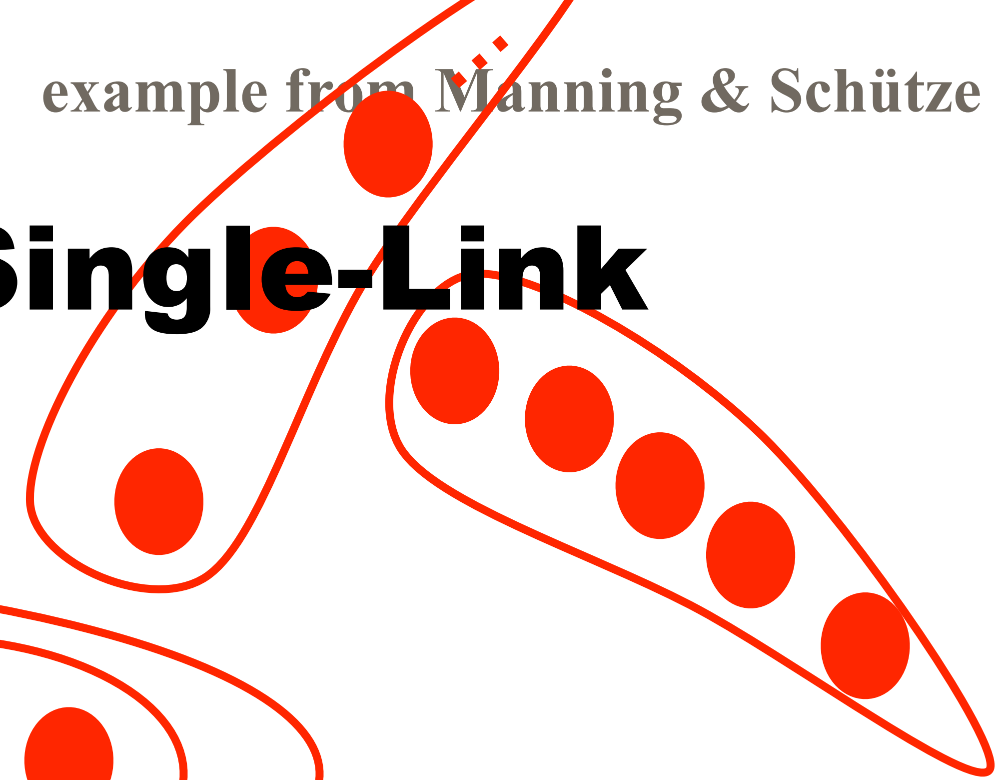

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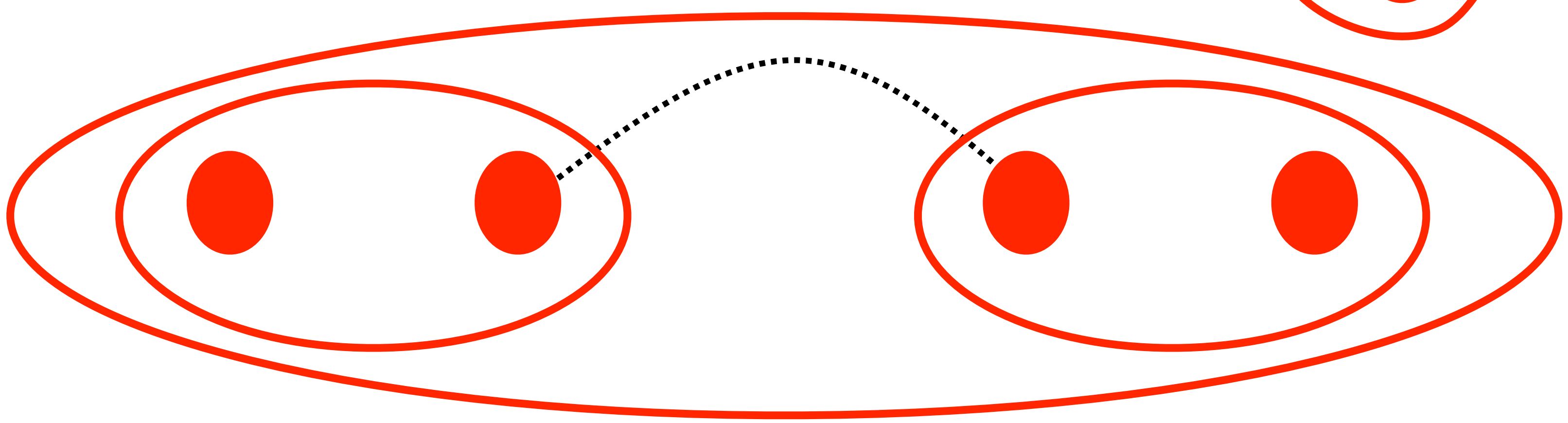

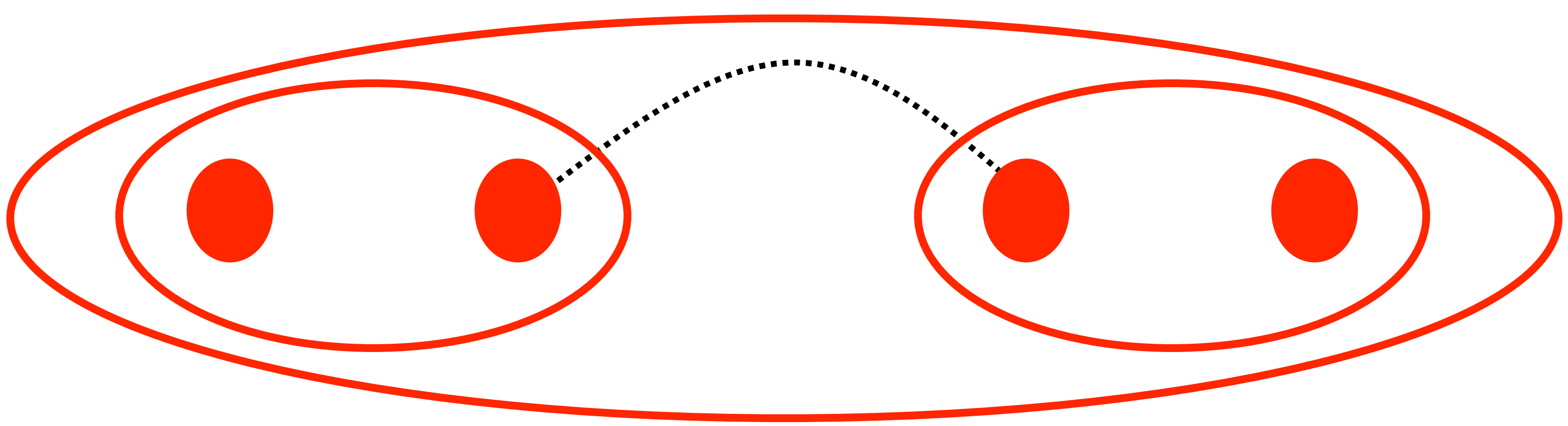

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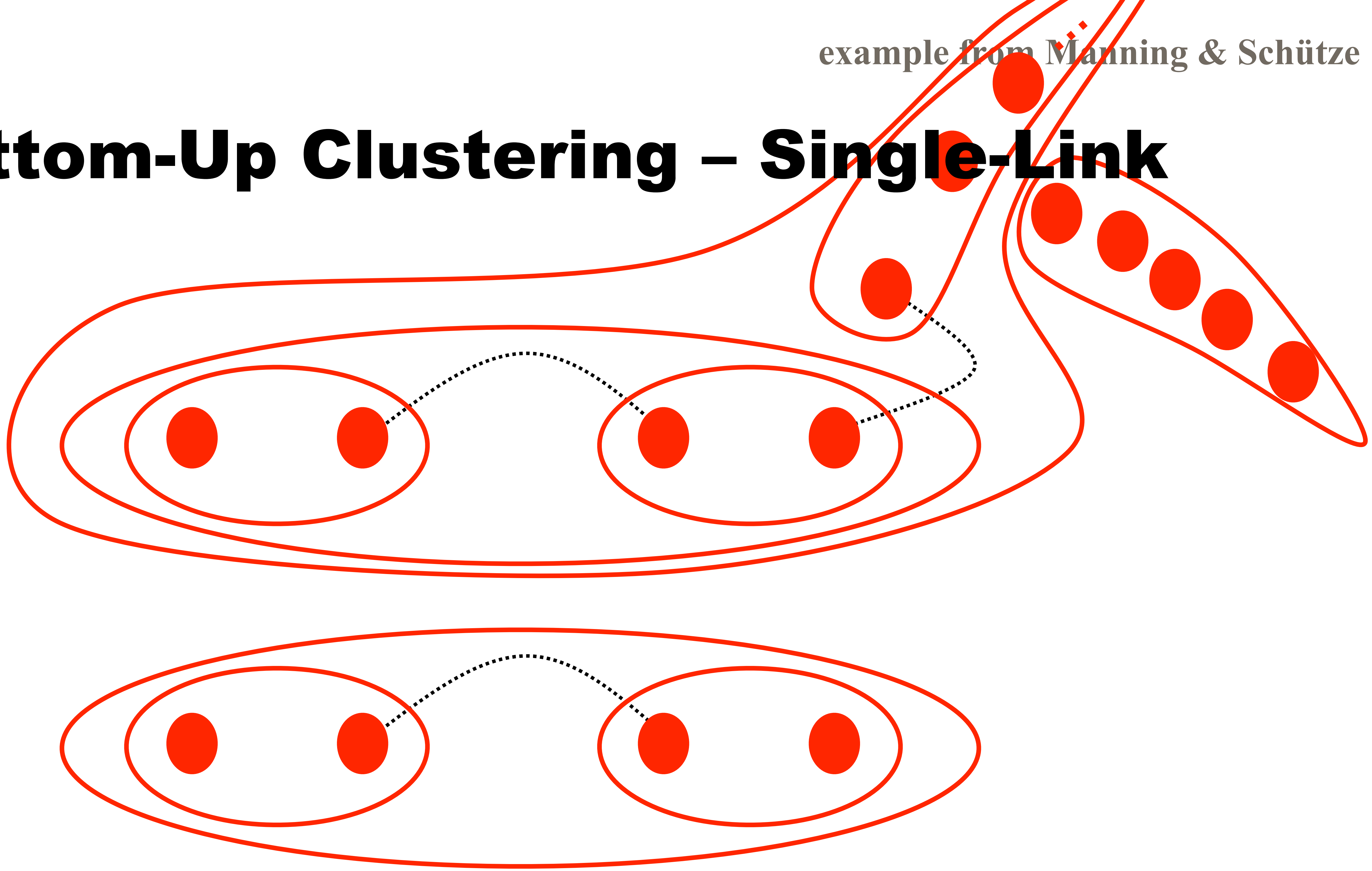

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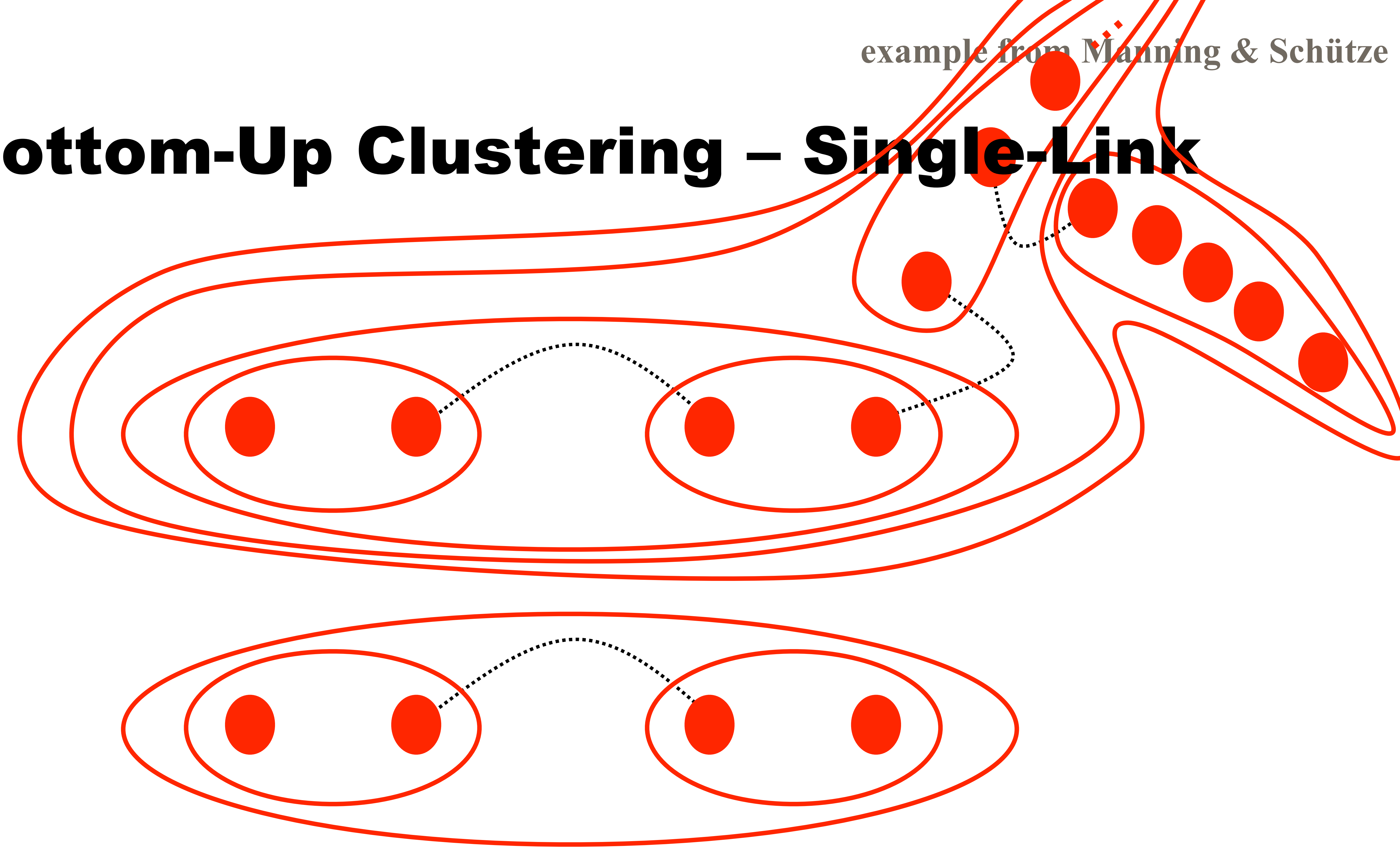

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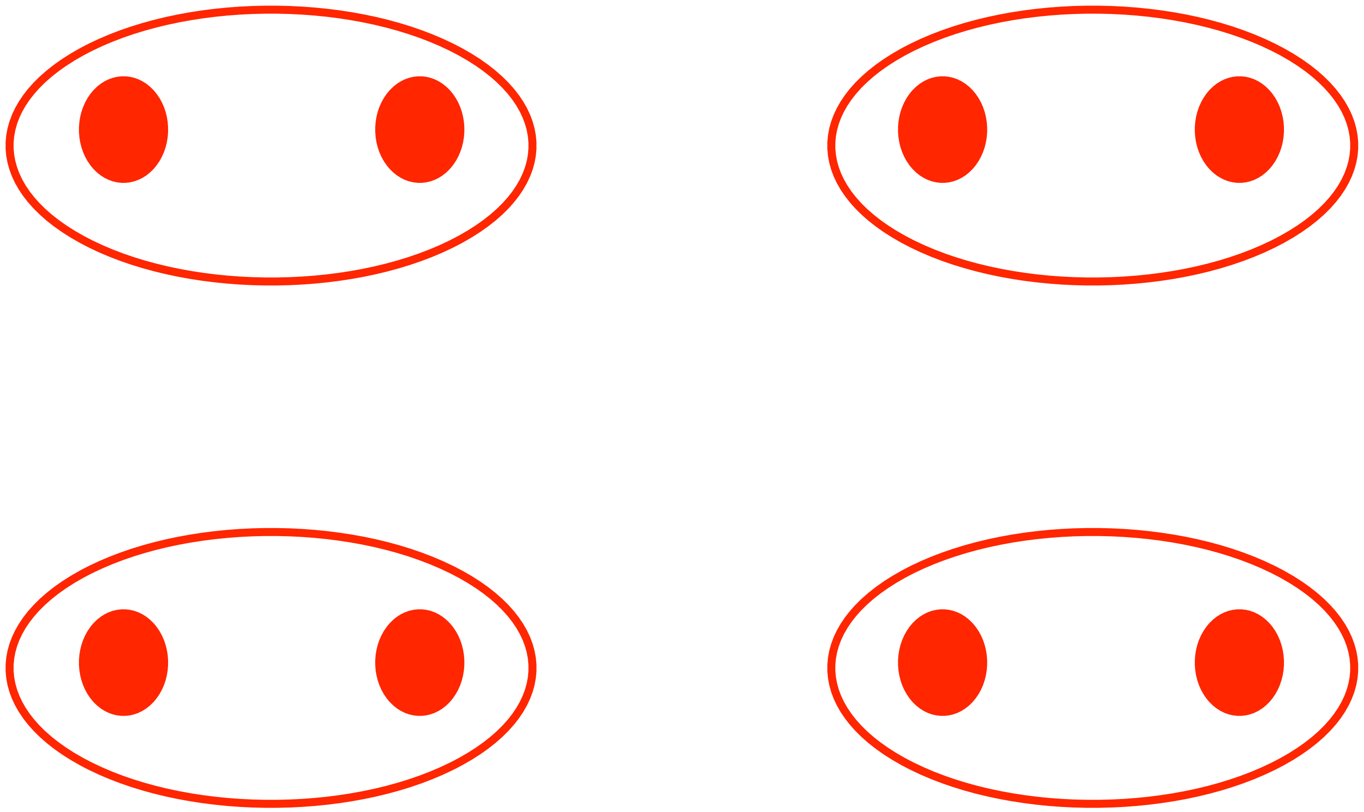

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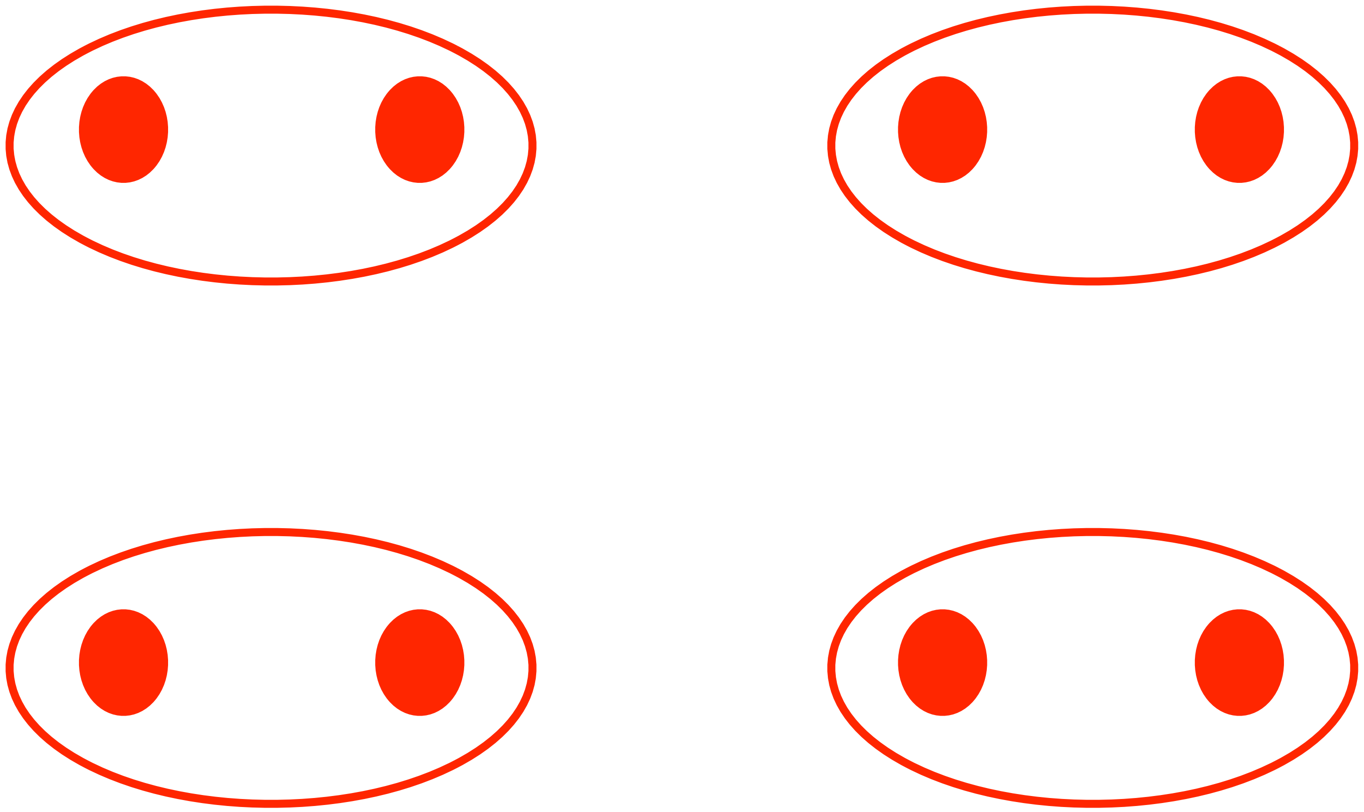

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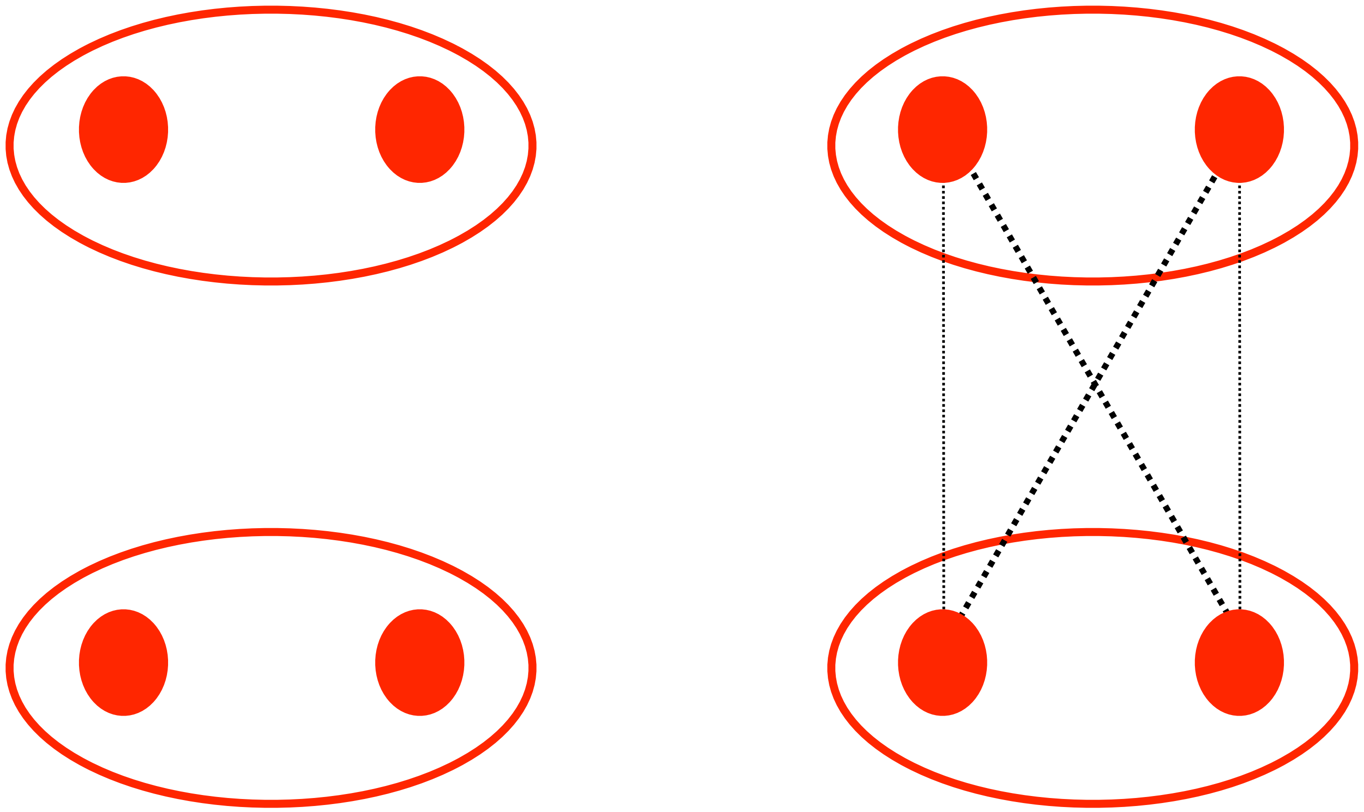

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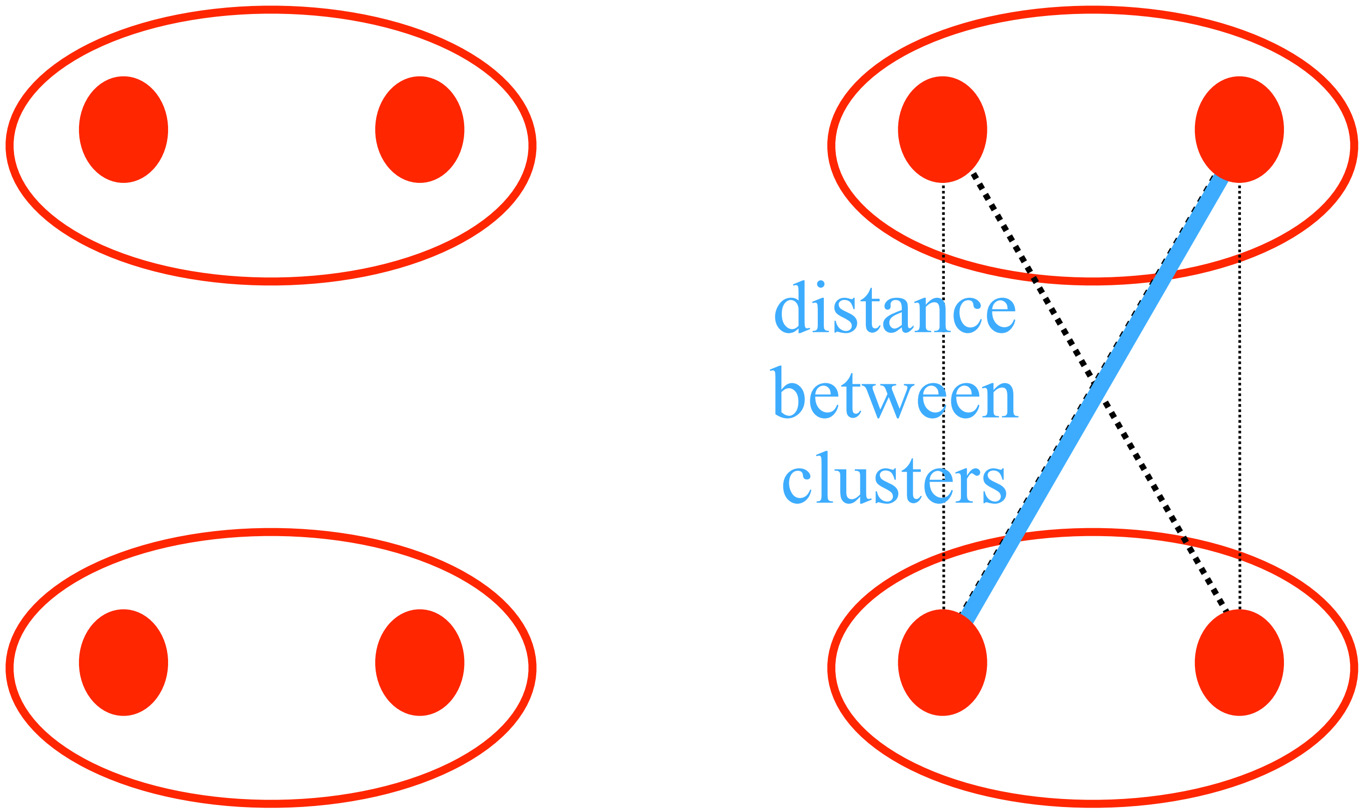

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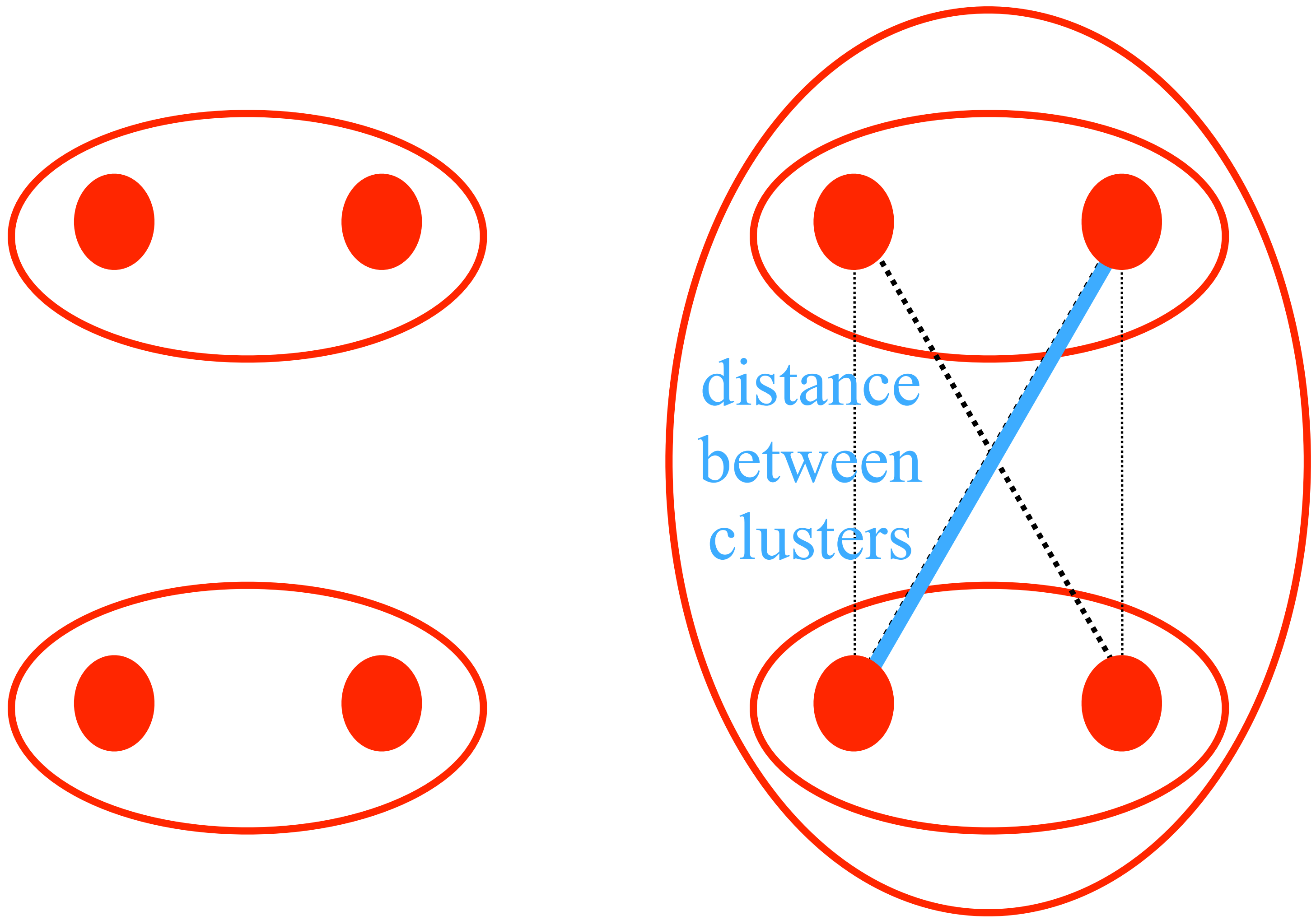

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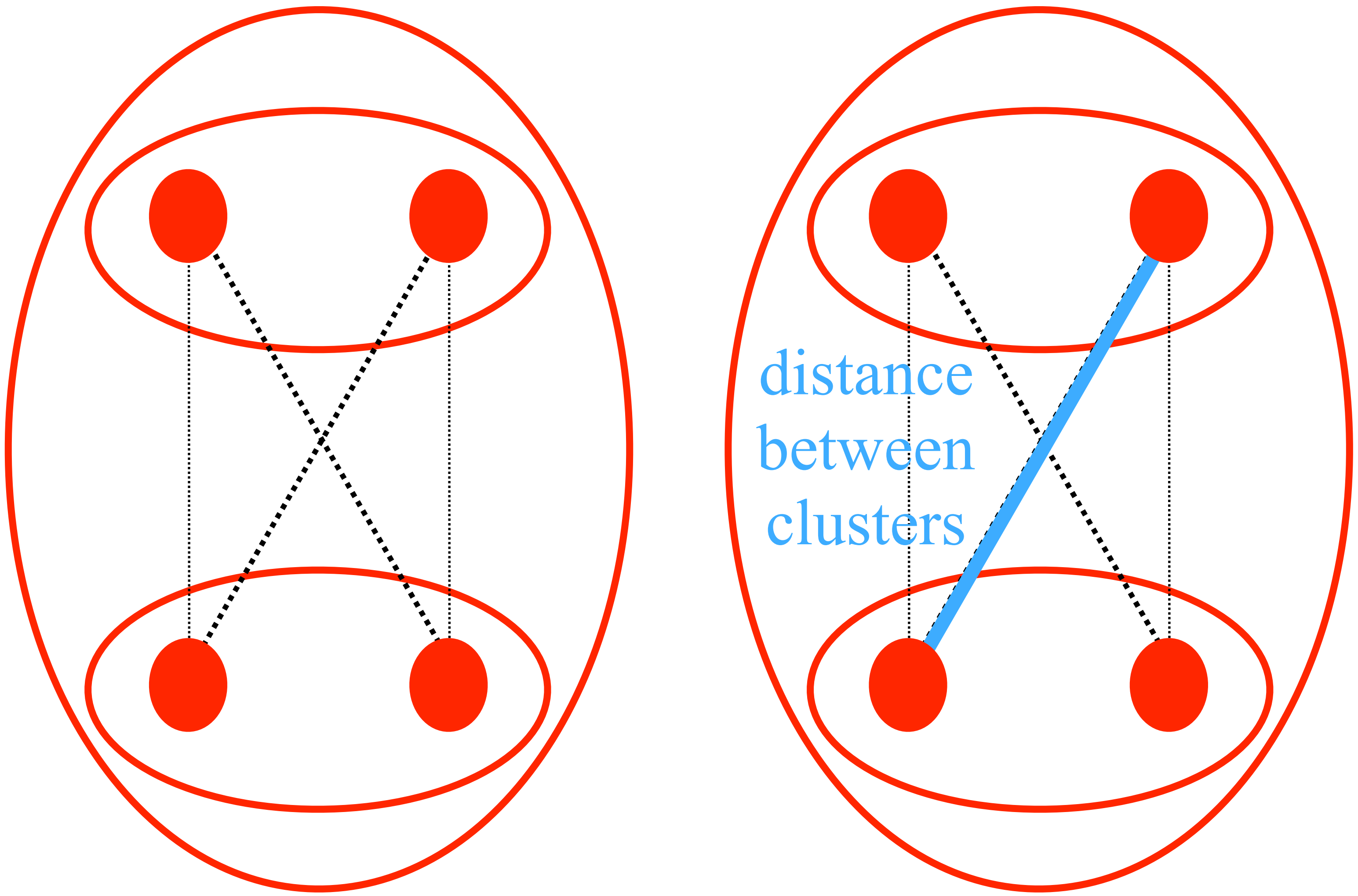

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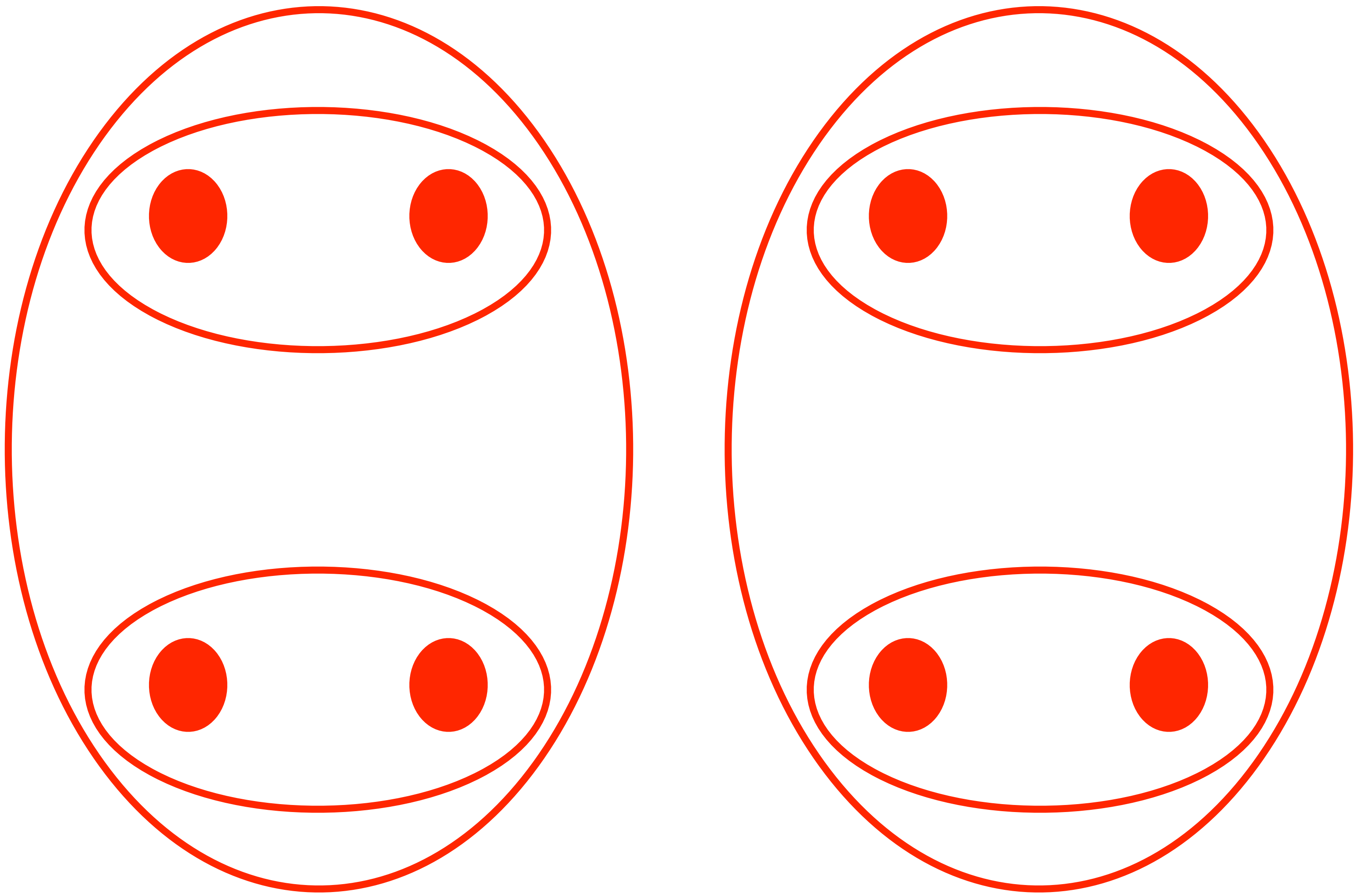
example from Manning & Schütze

Bottom-Up Clustering – Complete-Link



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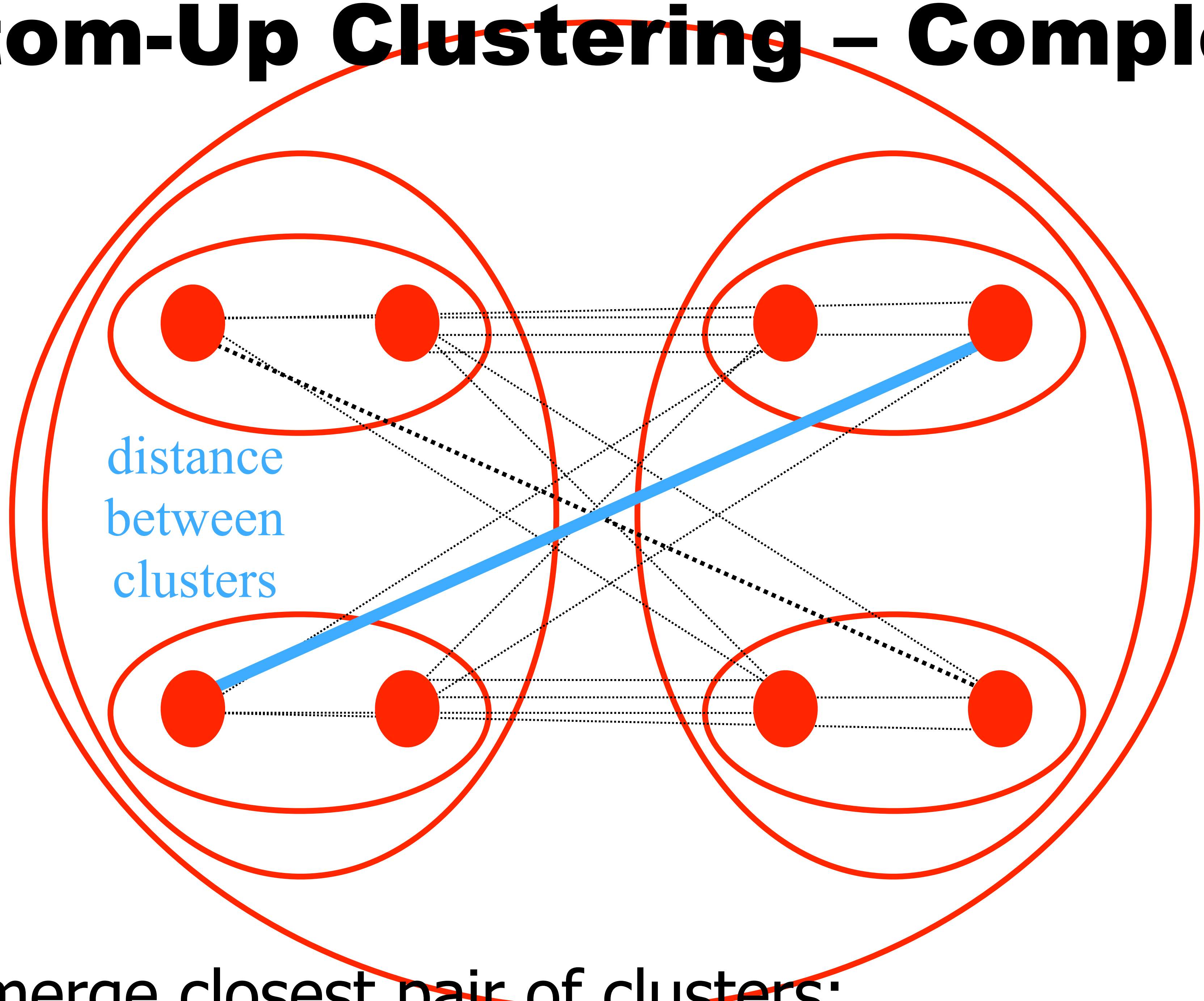

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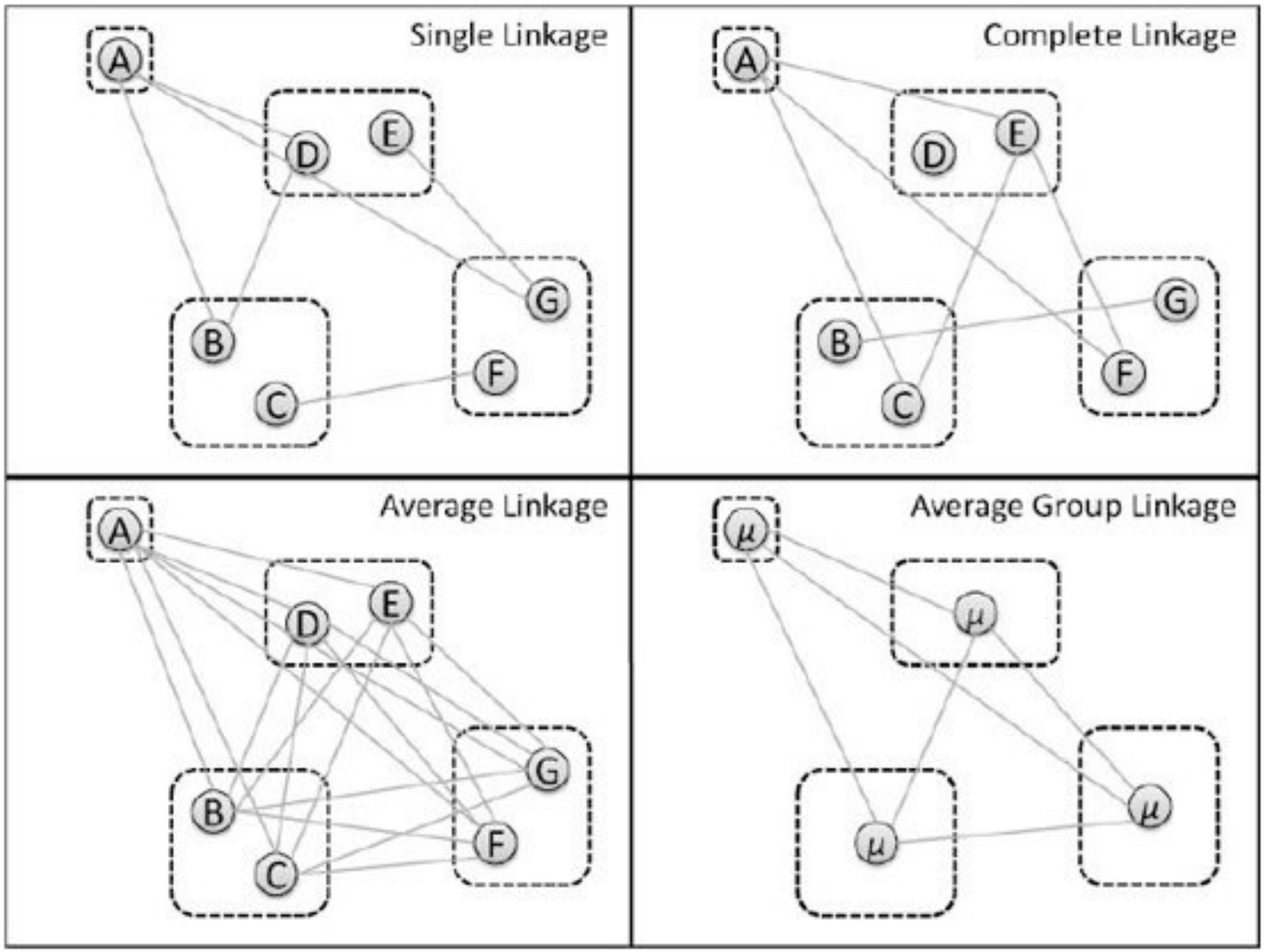
Bottom-Up Clustering Heuristics



Bottom-Up Clustering

- Start with one cluster per point
- Repeatedly merge 2 closest clusters
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- Some flexibility in defining dist(a,b)
  - Might not be Euclidean distance; e.g., use vector angle

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  - Viterbi version – called "k-means clustering"
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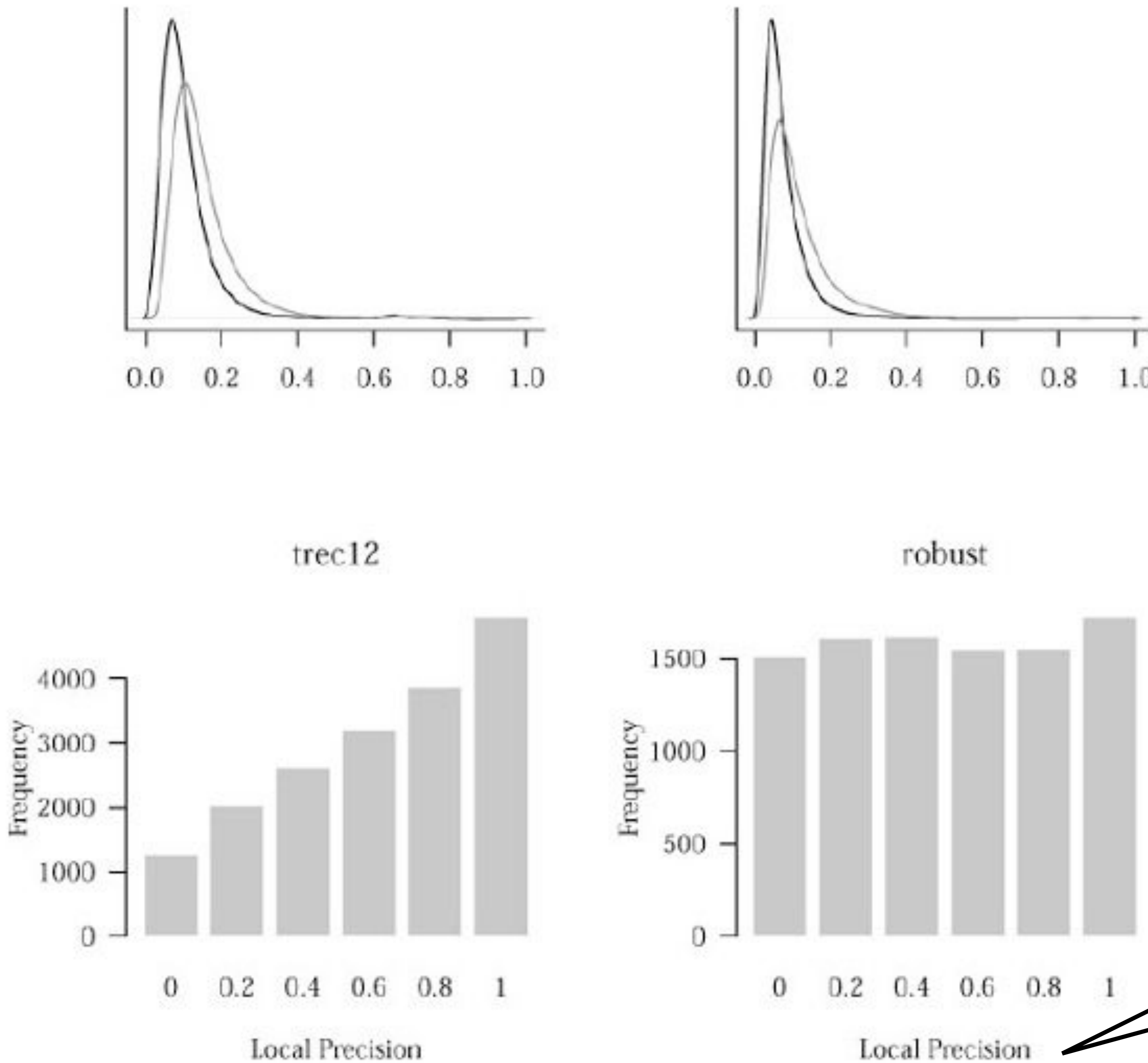
- Parameters: k points representing cluster centers
- Hidden structure: for each data point (word type), which center generated it?

Cluster Hypothesis

- Keith van Rijsbergen: "Closely associated documents tend to be relevant to the same requests."

Cluster Hypothesis



Precision in of the 5 nearest neighbors of relevant documents

But Does It Help Retrieval?

- Cluster retrieval

$$P(Q|C_j) = \prod_{i=1}^{n} P(q_i|C_j)$$

- Smoothing with hard clusters

$$P(w|D) = (1 - \lambda - \delta)\frac{f_{w,D}}{|D|} + \delta\frac{f_{w,C_j}}{|C_j|} + \lambda\frac{f_{w,Coll}}{|Coll|}$$

- Smoothing with soft clusters

$$P(w|D) = (1 - \lambda - \delta)\frac{f_{w,D}}{|D|} + \delta\sum_{C_j}\frac{f_{w,C_j}}{|C_j|}P(D|C_j) + \lambda\frac{f_{w,Coll}}{|Coll|}$$

- Last two more effective (cf. topic models)