Word Storms: Multiples of Word Clouds for Visual Comparison of Documents

Quim Castellá, Charles Sutton (WWW-2014)

Zoltán Szabó

Gatsby Unit, Tea Talk

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Motivation

- Vast number of documents on the web.
- Need for quick scanning.
- Word clouds (Google: 963.000 hits; LDA - 172.000 hits):
  - One of the most popular generators: Wordle.
  - Font size = frequency of the word.

Key Problem

- Word clouds are difficult to *compare* visually.
- Word storm:

  - made of word clouds,
  - word cloud = subset of documents,
  - allows efficient contrasting, comparison of documents.
  - **Goal**: visualize an entire corpus.

Cloud Examples

One cloud :=

- one document: comparing individual docs,
- one track of a conference: $\sim$ areas,
- papers from a given period: $\sim$ time evolution,
- one scientific field (+its subfield): $\sim$ hierarchical categories.

Guiding Principles

1. Each cloud should represent its own document.
2. Clouds should be easy to compare/contrast.
   $\Rightarrow$ Co-occuring words: similar
   - font size, color,
   - position, orientation.

Creating a Single Cloud: Notations

- Word cloud = set of words: $W = \{w_1, \ldots, w_M\}$.
- Each word $w \in W$ has a
  - position: $p_w = (x_w, y_w)$,
  - font size: s_w, color: c_w.
- Importance of a word (=:its weight): tf.
  - W = words with the top M weights.

Creating a Single Cloud

- Font size $\propto$ word weight.
- Color, orientation: random.
- Position: spiral algorithm (next slide).

Creating a Single Cloud: Spiral Algorithm

- Given: word cloud with $i-1$ words.
- New word w to the desired/random location:
  - If
    - no intersection with previous words, and
    - $\in$ frame, then goto next word.
  - Else: w is moved outward until a valid position.

Spiral Algorithm: Formally

Algorithm 1 Spiral Algorithm

Require: Words W, optionally positions $\mathbf{p} = \{p_w\}_{w \in W}$
Ensure: Final positions $\mathbf{p} = \{p_w\}_{w \in W}$

for all words $w \in \{w_1, \ldots, w_M\}$ **do**
    if initial position p_w unsupplied, sample from Gaussian
    count $\leftarrow 0$
    while p_w not valid $\wedge$ count $<$ Max Iteration **do**
        Move p_w one step along a spiral path
        count $\leftarrow$ count $+ 1$
    end while
    if p_w not valid **then**
        Restart with a larger frame
    end if
end for

Creating a Storm

- i^{th} document: $u_i = (u_{iw})$: count of word w in the i^{th} doc.
- i^{th} word cloud: $v_i = (W_i, \{p_{iw}\}, \{c_{iw}\}, \{s_{iw}\})$.
- Alg-1:
  - Color: α-channel = idf = $\log\left(\frac{|\text{docs}|}{|\text{docs containing } w|}\right)$.
    $\Rightarrow$ transparent: the word appears in many docs.
  - Locations:
    - Initialization: spiral method.
    - Iterate: desired locations := $\hat{\mathbb{E}}_{clouds}$[previous locations].

Coordinated Layout: Alg-1

Algorithm 2 Iterative Layout Algorithm

Require: Storm $v_i = (W_i, \{c_{iw}\}, \{s_{iw}\})$ without positions
Ensure: Word storm $\{v_1, \ldots, v_N\}$ with positions

1: **for** $i \in \{1, \ldots, N\}$ **do**
2: $\quad \mathbf{p}_i \leftarrow \text{SpiralAlgorithm}(W_i)$
3: **end for**
4: **while** Not Converged $\wedge$ count $<$ Max Iteration **do**
5: $\quad$ **for** $i \in \{1, \ldots, N\}$ **do**
6: $\quad\quad p'_{iw} \leftarrow \frac{1}{|\mathcal{V}_w|} \sum_{v_j \in \mathcal{V}_w} p_{jw}, \quad \forall w \in W_i$
7: $\quad\quad \mathbf{p}_i \leftarrow \text{SpiralAlgorithm}(W_i, \mathbf{p}'_i)$
8: $\quad$ **end for**
9: $\quad$ count = count + 1
10: **end while**

Problem: tends to move words far away from center.

Coordinated Layout: Alg-2 – Objective

- Set of documents: $u_{1:N} = \{u_1, \ldots, u_N\}$. Storm: $v_{1:N} = \{v_1, \ldots, v_N\}$.
- Objective (how well the storm fits the corpus):

$$f_{u_{1:N}}(v_{1:N}) = \underbrace{\sum_{i,j=1}^{N} [d_u(u_i, u_j) - d_v(v_i, v_j)]^2}_{\text{similar docs are mapped to similar clouds}} + \underbrace{\sum_{i=1}^{N} c(u_i, v_i)}_{\text{faithful repr. of the own doc}}.$$

- First term: MDS. d_u: Euclidean distance. $\kappa \geq 0$

$$d_v(v_i, v_j) = \sum_{w \in W_i \cup W_j} (s_{iw} - s_{jw})^2 + \kappa \sum_{w \in W_i \cap W_j} \left\| p_{iw} - p_{jw} \right\|_2^2.$$

- Second term:

$$c(u_i, v_i) = \sum_{w \in W_i} (u_{iw} - s_{iw})^2.$$

Coordinated Layout: Alg-2 – Objective

- Two more penalties ($\lambda > 0$, $\mu > 0$):

$$r(v_{1:N}) = \lambda \underbrace{\sum_{i=1}^{N} \sum_{w,w' \in W_i} O^2_{i:w,w'}}_{\text{words do not overlap}} + \mu \underbrace{\sum_{i=1}^{N} \sum_{w \in W_i} \|p_{iw}\|_2^2}_{\text{compact configuration}}.$$

  $O_{i:w,w'}$: minimum distance required to separate overlapping words (w, w').

- Final objective: $f_{u_{1:N}}(v_{1:N}) + r(v_{1:N}) \to \min_{v_{1:N}}$.
- Optimization:
  - homotopy scheme in λ,
  - fixed subtask: gradient descent.

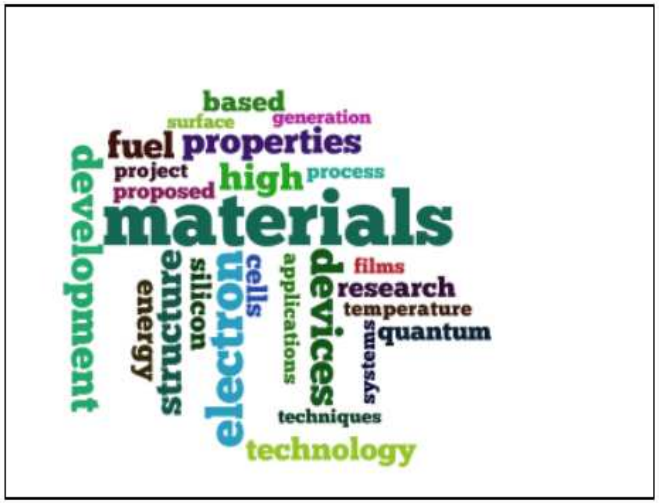
Coordinated Layout: Combined Algorithm

- Iterative algorithm: fast, but not compact.
- Gradient method: compact storm, but slow.
- In practise: combination gives decent results.

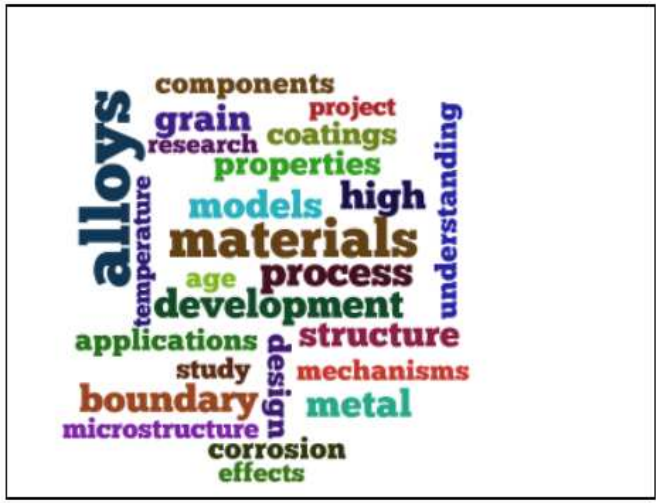
Numerical Illustration

- User study: users are better in
  - outlier document detection,
  - the discovery of the two most similar documents.
- ICML-2012:
  - visualization of sessions,
  - `http://icml.cc/2012/whatson-all/`.
- Research grant abstract visualization (EPSRC):
  - $1 - 5^{th}$ = material sciences, 6^{th} = maths.
  - independent vs. coordinated layout.

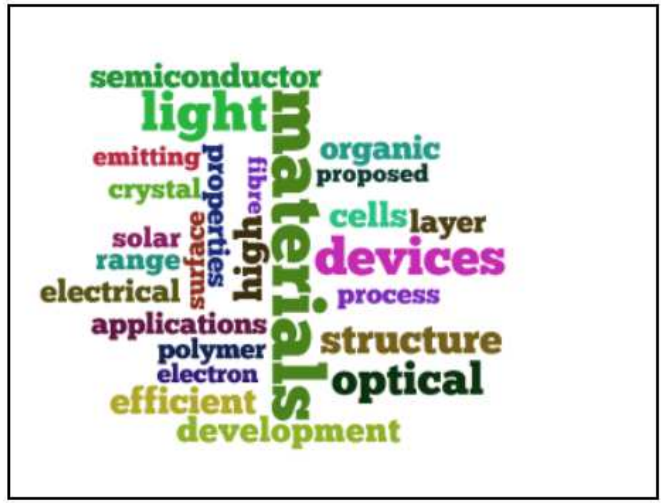
EPSRC programmes: independent clouds



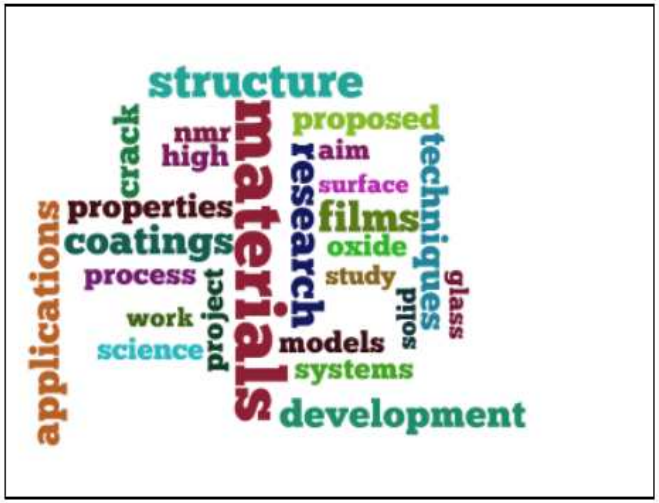
(a) Electronic Materials



(b) Metals and Alloys

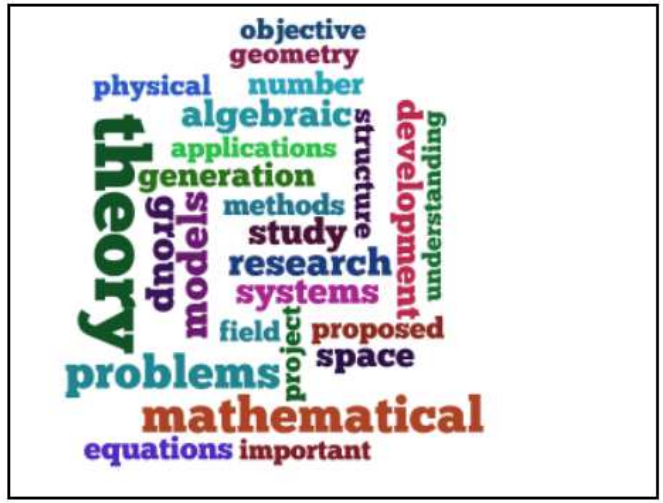


(c) Photonic Materials



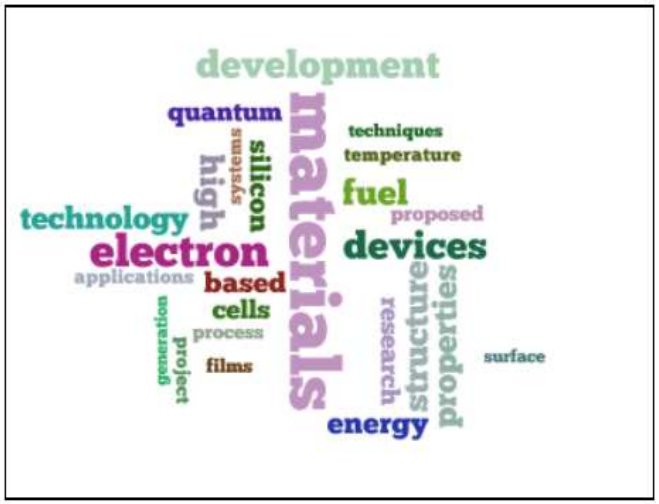
(d) Structural Ceramics and Inorganics

(e) Structural Polymers and Composites

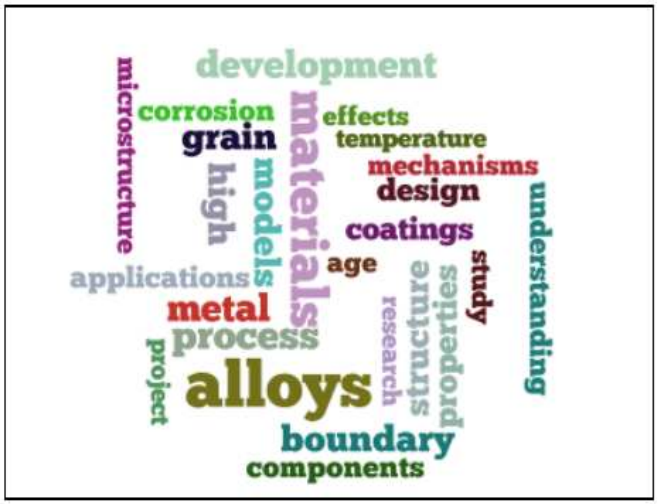


(f) Mathematical Sciences

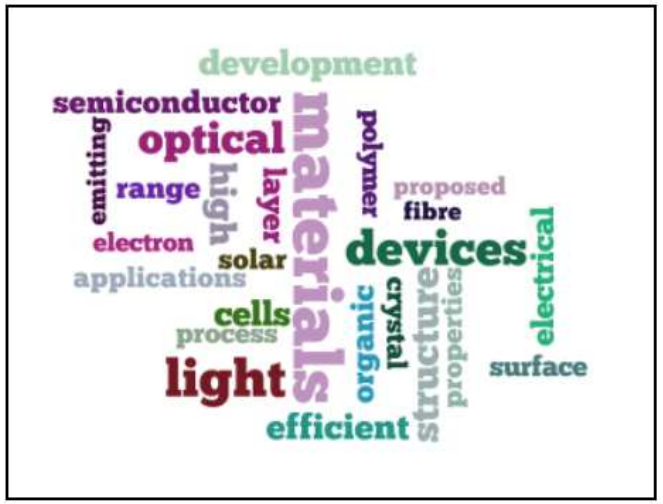
EPSRC programmes: coordinated storm



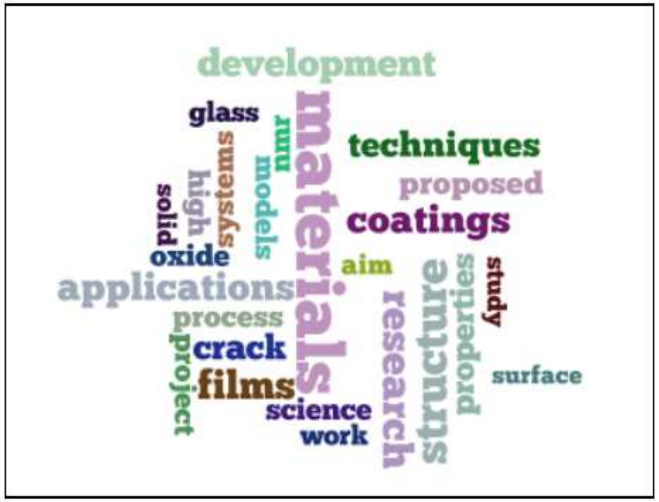
(a) Electronic Materials



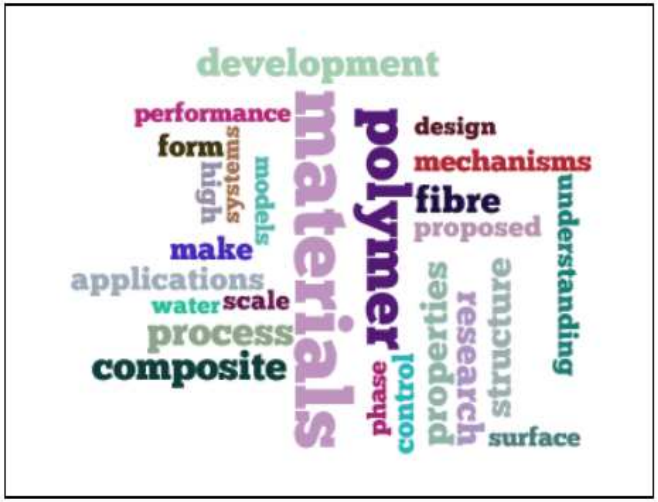
(b) Metals and Alloys



(c) Photonic Materials



(d) Structural Ceramics and Inorganics



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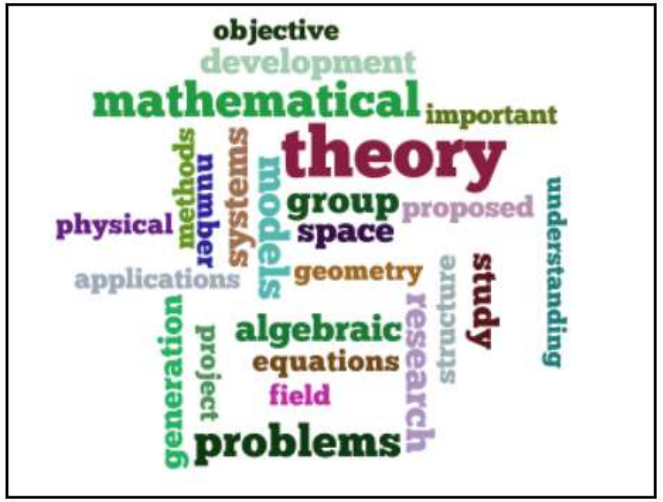

(f) Mathematical Sciences

Coordinated Storm: Interpretation

- (a)-(e) similar: 'material', 'applications', 'properties'.
- Contrast, absence of words:
  - 'coating' only in (b) and (d),
  - no 'material' in (f).
- Informative words (transparency): 'electron' (a), 'metal' (b), 'light' (c), 'crack' (d), 'composite' (e), 'problems' (f).

Summary

- Independent word clouds are difficult to compare.
- Word storm:
  - Similar clouds represent similar documents.
  - Emphasizes the most informative words.
  - Useful in comparing/contrasting documents.
- Source code: `http://groups.inf.ed.ac.uk/cup/wordstorm/wordstorm.html`