# Signal Processing on Databases

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## Lecture 1: Using Associative Arrays

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# Outline

- Citation Data
  - Schema
  - Pipeline
  - Observations
- Graph Construction
- Multi-Hyper Graphs
- Summary

# Exploded Schema (Key Table)

### Input Data

| ut | auth | docid | ref.docid |
|---|---|---|---|
| 1234 | a | | a |
| 1243 | b | b | |
| 4321 | | c | c |

### Accumulo Table: TkeyT

| | ut/1234 | ut/1243 | ut/4321 |
|---|---|---|---|
| auth/a | 1 | | |
| auth/b | | 1 | |
| docid/b | | 1 | |
| docid/c | | | 1 |
| ref.docid/a | 1 | | |
| ref.docid/c | | | 1 |

| | auth/a | auth/b | docid/b | docid/c | ref.docid/a | ref.docid/c |
|---|---|---|---|---|---|---|
| ut/1234 | 1 | | | | 1 | |
| ut/1243 | | 1 | 1 | | | |
| ut/4321 | | | | 1 | | 1 |

### Accumulo Table: Tkey

- Holds structured citation data
- Primary table for constructing graphs
- Values hold position in record (i.e. 1st, 2nd, 3rd author/reference …)

# Exploded Schema (Txt Table)

## Accumulo Table: Ttxt

| | ref | title | abstract |
|---|---|---|---|
| ref.docid/1234 | a | | |
| ut/1243 | b | b | b |
| ut/4321 | | c | c |

- Traditional table for holding long formatted reference, title, and abstract strings
- Eliminates inconvenient long strings from key table
- Typically only used for manual verification

# Exploded Schema (Ngram Table)

### Input Data

| ut | title | abstract |
|---|---|---|
| 1234 | a b a … | c d … |
| 1243 | b … | |
| 4321 | | d … |

### Accumulo Table: TngramT

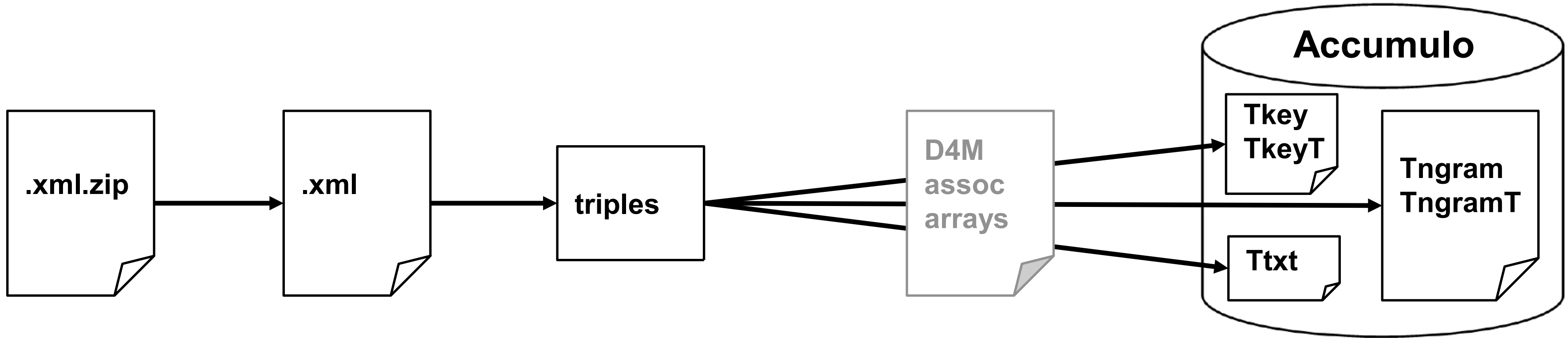
| | ut/1234 | ut/1243 | ut/4321 |
|---|---|---|---|
| title/1gram/a | 1,3 | 1 | |
| title/1gram/b | 2 | | |
| title/2gram/a b | 1 | | |
| abstract/1gram/c | 1 | | |
| abstract/1gram/d | 2 | | 1 |
| abstract/2gram/c d | 1 | | |

| | title/1gram/a | title/1gram/b | title/2gram/a b | abstract/1gram/c | abstract/1gram/d | abstract/2gram/c d |
|---|---|---|---|---|---|---|
| ut/1234 | 1,3 | 2 | 1 | 1 | 2 | 1 |
| ut/1243 | 1 | | | | | |
| ut/4321 | | | | | 1 | |

### Accumulo Table: Tngram

- Holds 1, 2, 3-grams for titles and abstract (5x larger than key table)
- Values hold word position(s) in record
- Separation allows ngram ingest to be done independently

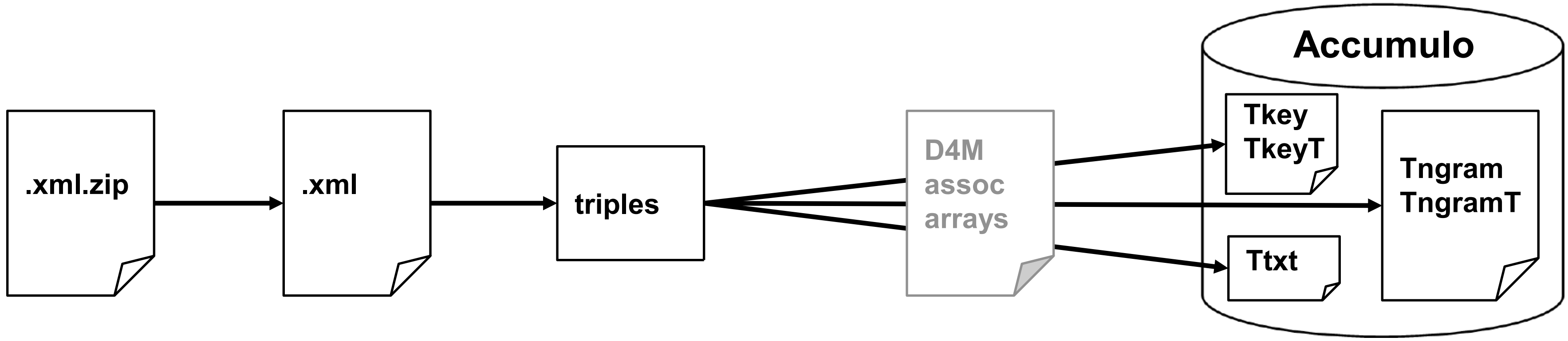
# Typical Processing Chain




1. Uncompressed XML file [once]
2. Read XML into binary structure and parse into triples [a few times to finalize parse code]
3. Construct D4M associative arrays from triples to check data [once]
4. Insert triples into Accumulo [once per database]

- Used several intermediate files so that fewest steps need to be redone during development

# Single Node 42M Record Times



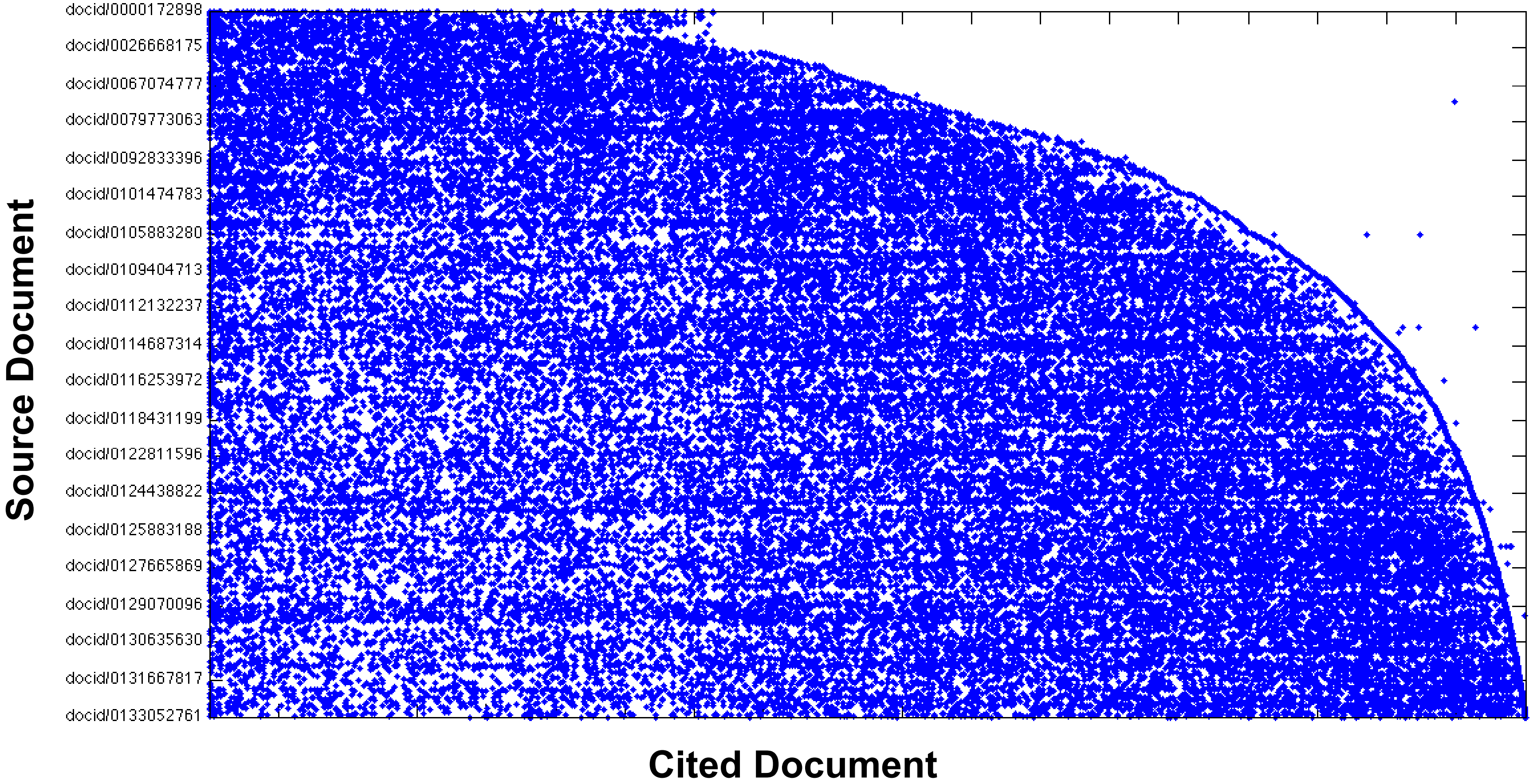

1. Uncompress XML file [~1 hour]
2. Read XML into binary structure and parse into triples [~2 hours]
3. Construct D4M associative arrays from triples to check data [~1 day]
4. Insert triples into Accumulo [key ~2 days, txt ~1 day, ngram ~10 days]

- Single node sustained insert rate of 10,000 – 100,000 entries/sec.
- Performance is sufficient that entire data set can be hosted on a single node

# Outline

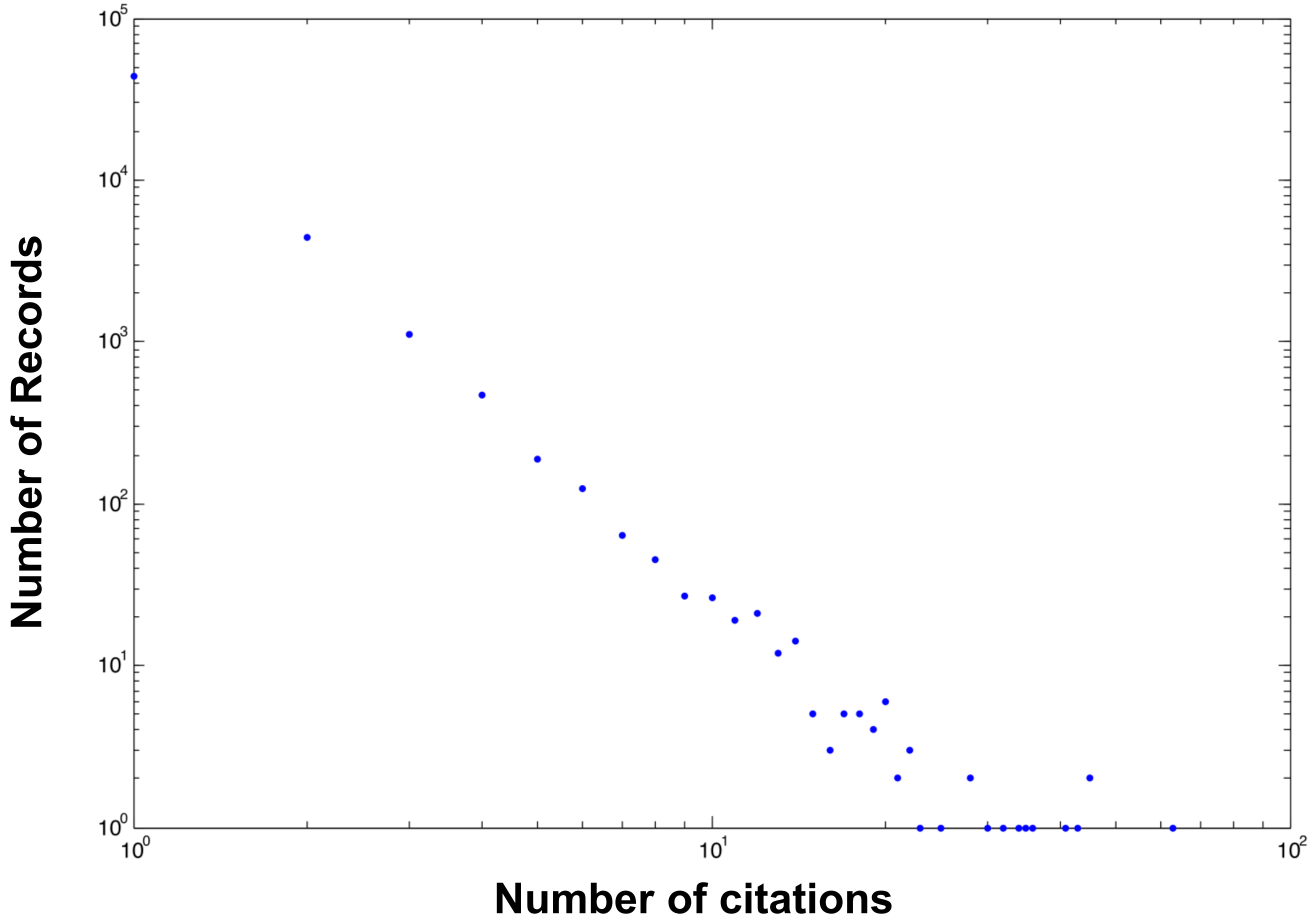
- Citation Data
- Graph Construction
  - Citation
  - Author
  - Institution
  - Keyword
  - Uncertainty
  - Pedigree
- Multi-Hyper Graphs
- Summary

# Adjacency Matrix




- **Document ID increases with time (as expected)**

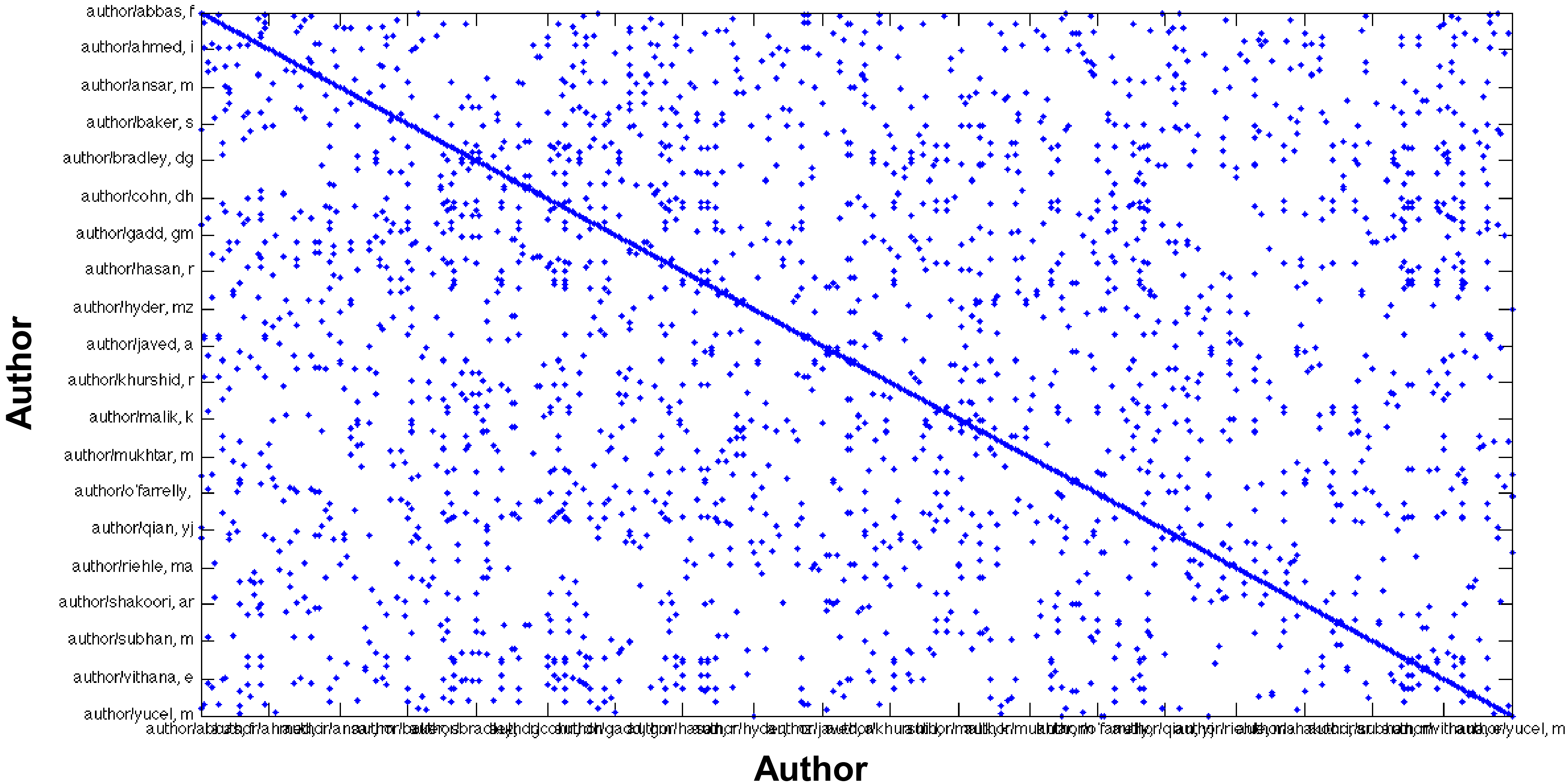
# Degree Distribution




- **Power law (as expected)**

# Author Graph

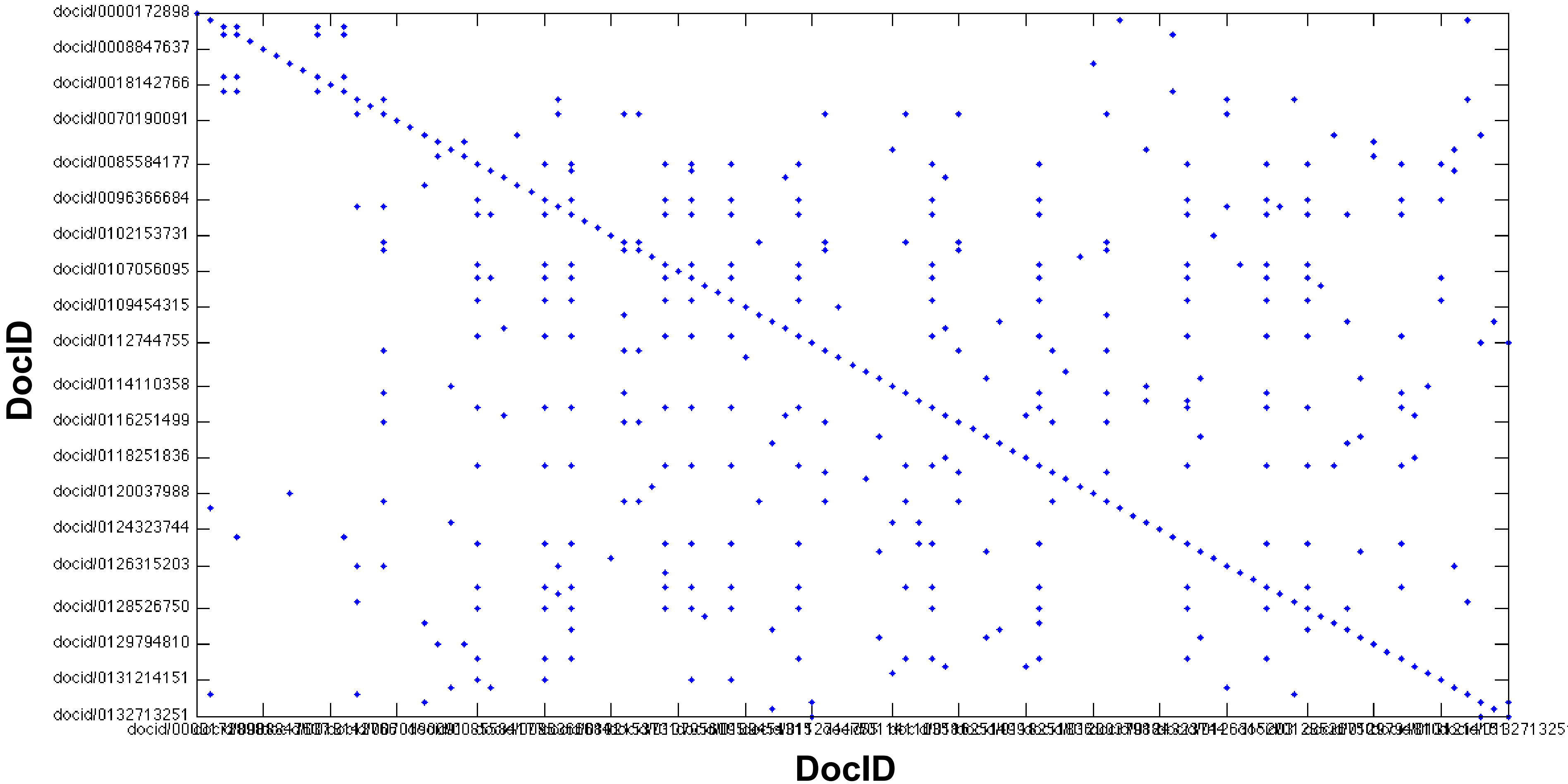
**E(:,StartsWith('author/,'))$^t$ * E(:, StartsWith('author/'))**




- **Counts how many times a pair of Authors are in the same DocID**

# Author DocID Graph

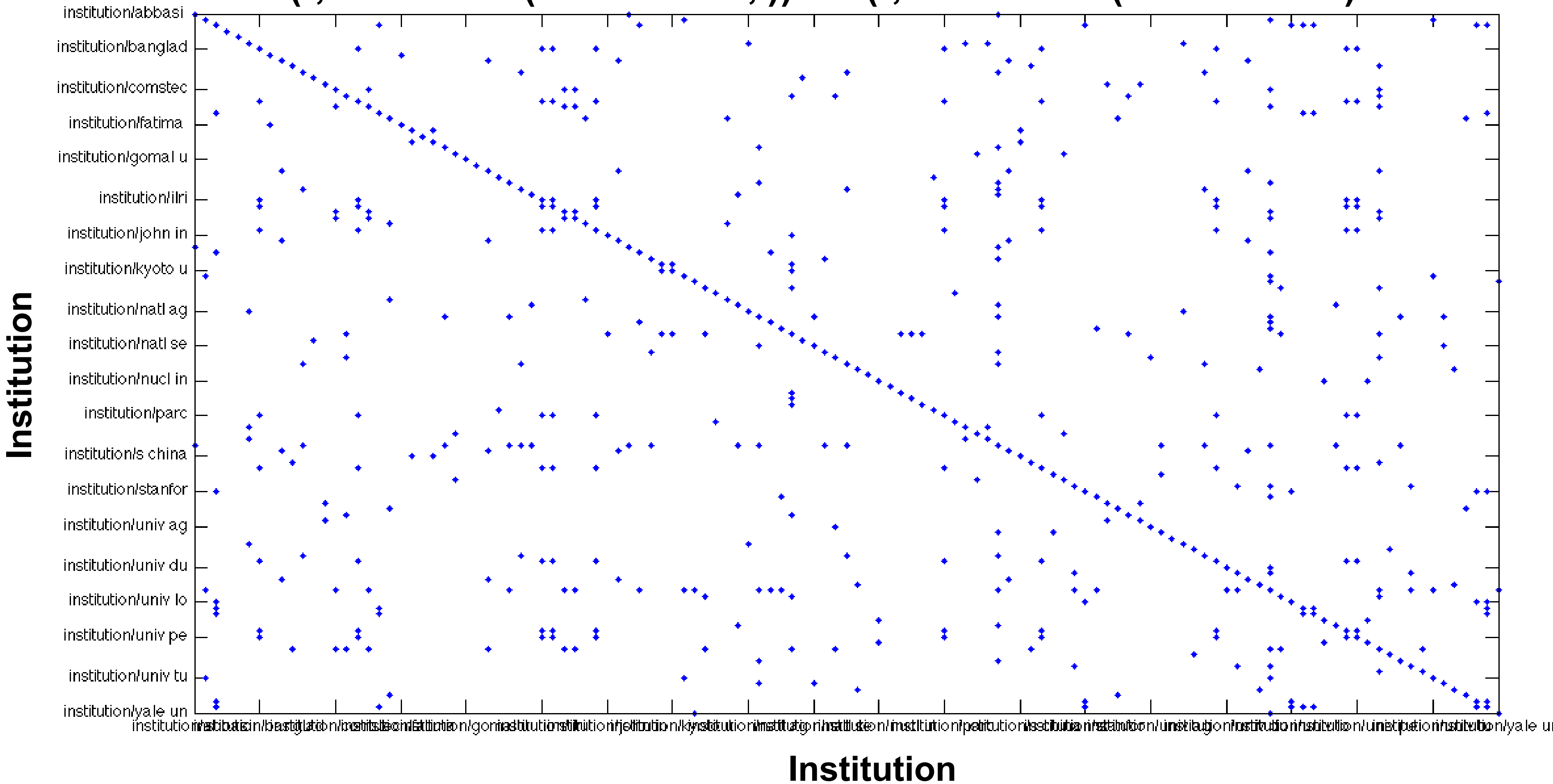
## E(:,StartsWith('author/,')) * E(:, StartsWith('author/')$^t$




- **Counts how many times a pair of DocIDs share an Author**

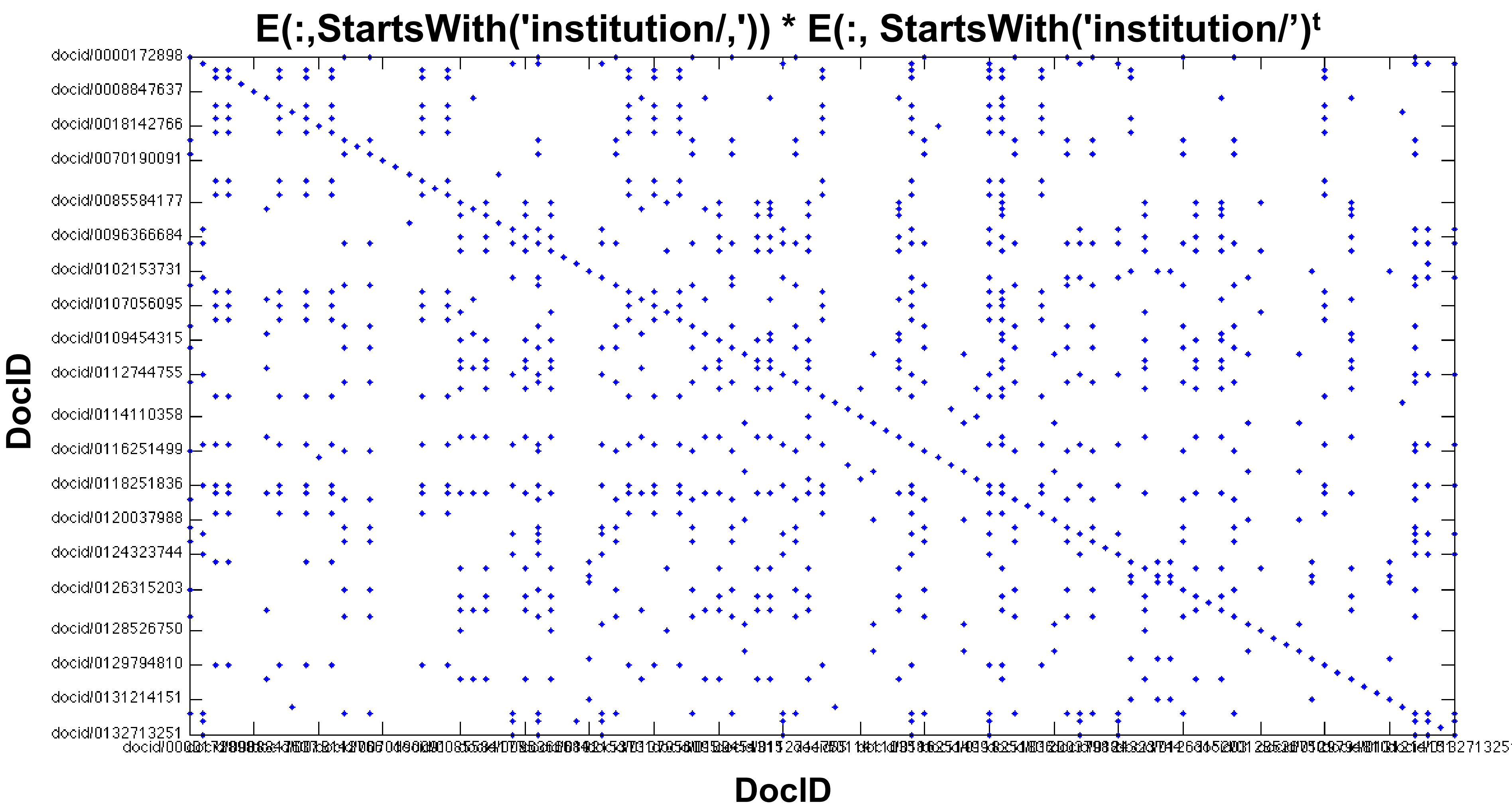
# Institution Graph

## $E(:,\mathrm{StartsWith}(\text{'institution/,'}))^{t} * E(:, \mathrm{StartsWith}(\text{'institution/'}))$



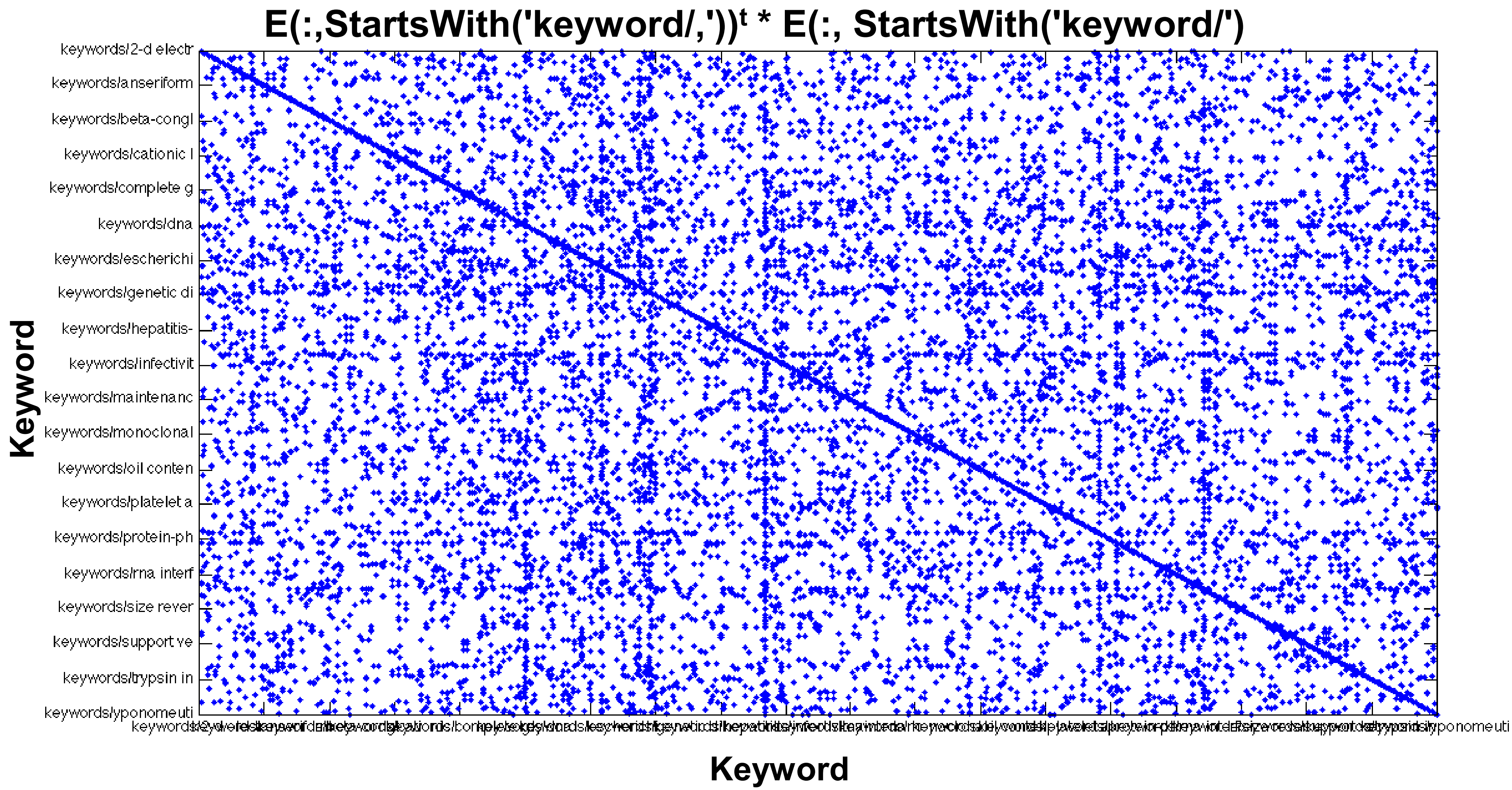

- **Counts how many times a pair of Institutions are the same DocID**

# Institution DocID Graph




- Counts how many times a pair of DocIDs share an Institution

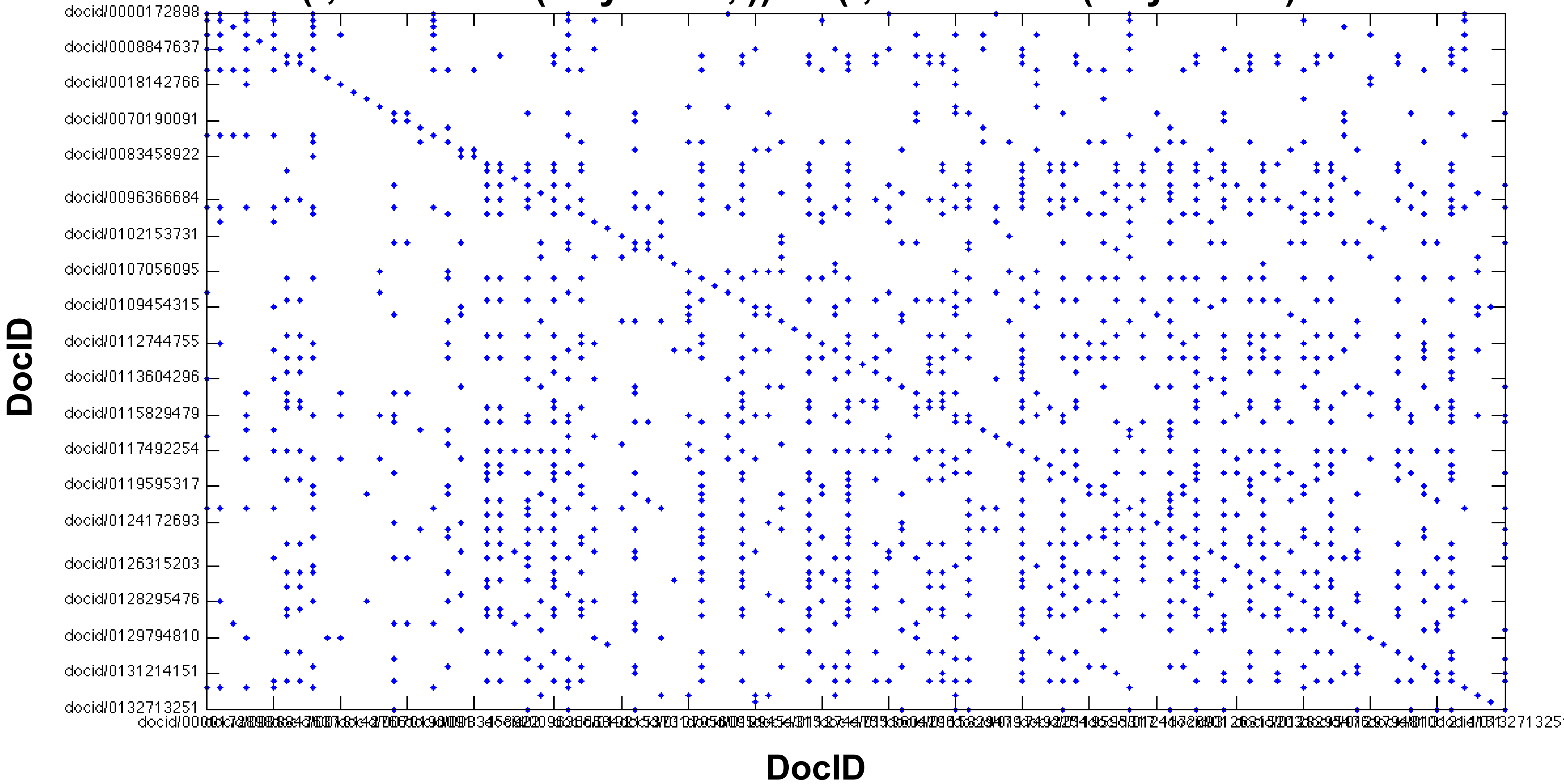
# Keyword Graph




- **Counts how many times a pair of Keywords are in the same DocID**

# Keyword DocID Graph

$E(:,\text{StartsWith}('keyword/,')) * E(:, \text{StartsWith}('keyword/'))^t$

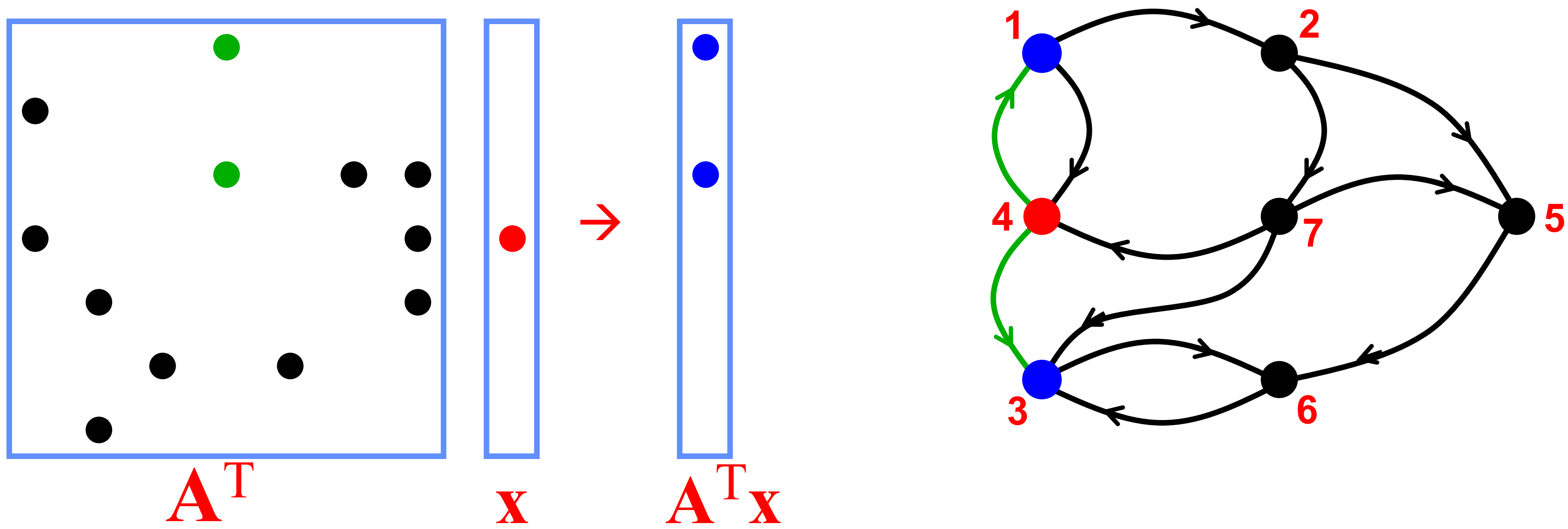



- **Counts how many times a pair of DocIDs share a Keyword**

# Outline

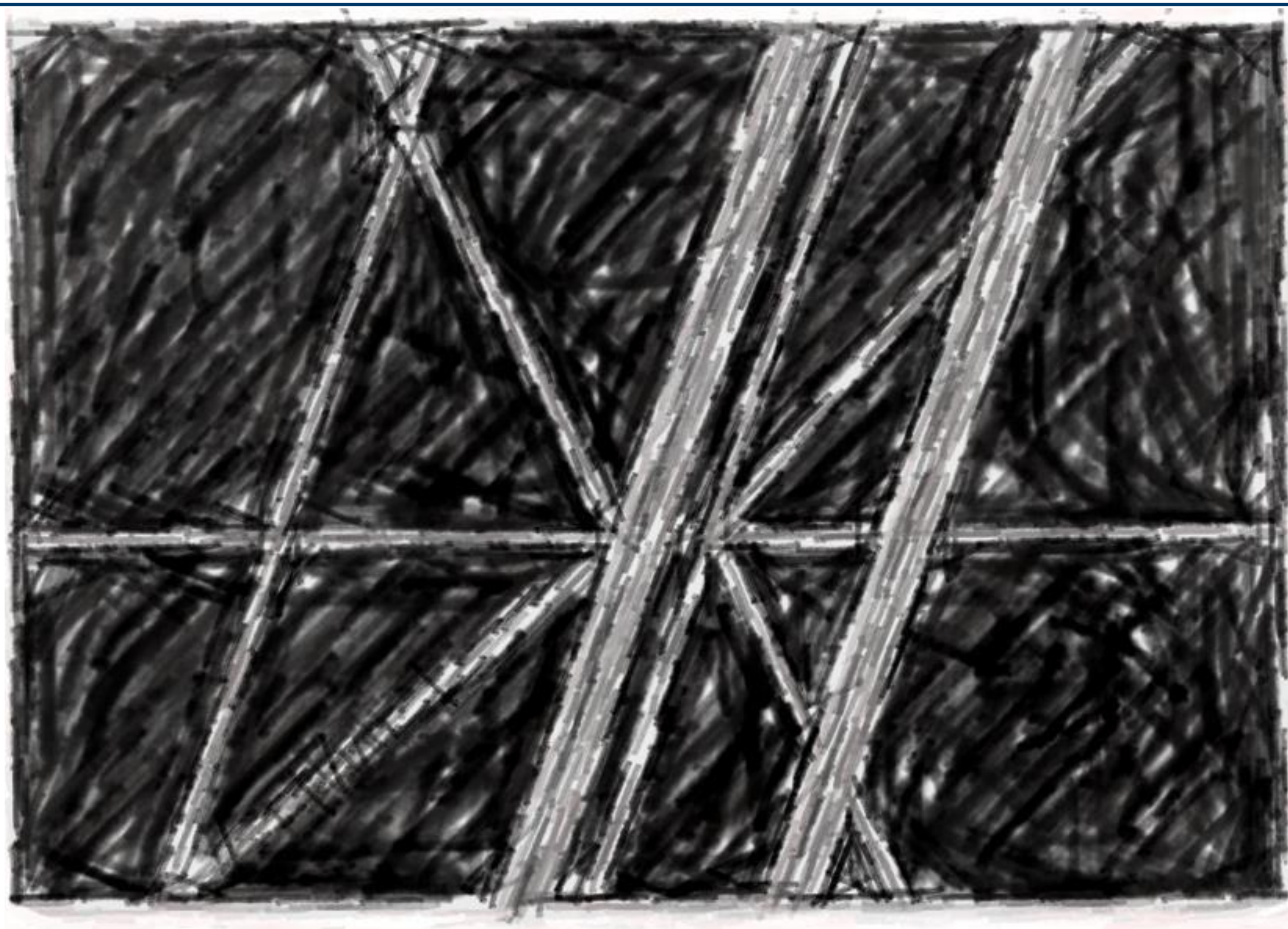
- Citation Data
- Graph Construction
- Multi-Hyper Graphs
  - Undirected
  - Directed
  - Multi
  - Hyper
- Summary

# Directed Graph




- Directed graphs can be represented as a sparse matrices
  - Multiply by adjacency matrix – step to neighbor vertices
  - Work-efficient implementation from sparse data structures
- The real world is far more complex than directed graphs
  - Directed, multi, hypergraphs

# Digraphs are Black & White



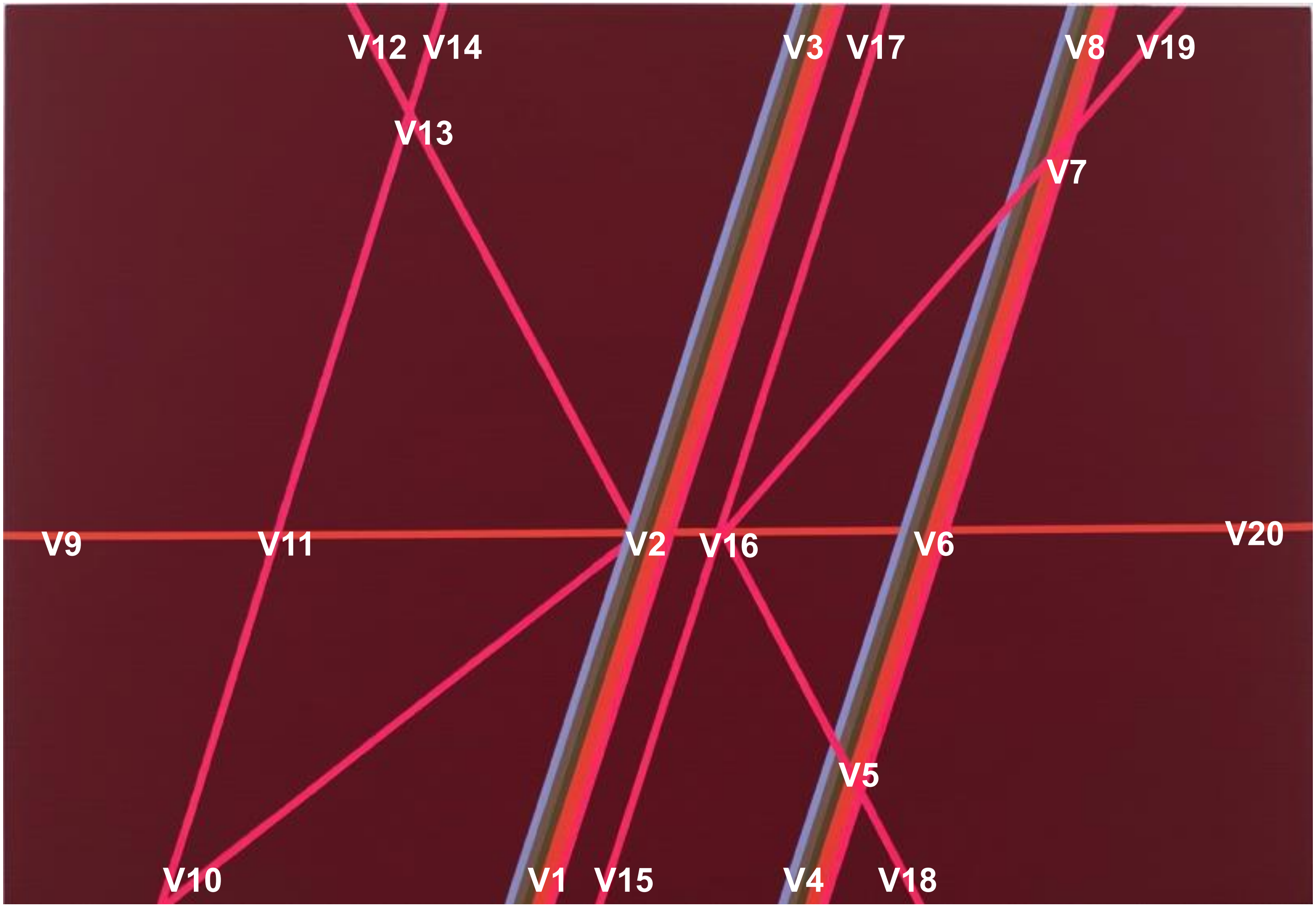
# The World is Color

**Artist: Ann Pibal; Painting: “XCRS”**

# 5 Edge Colors


**Artist: Ann Pibal; Painting: “XCRS”**

# 20 Vertices

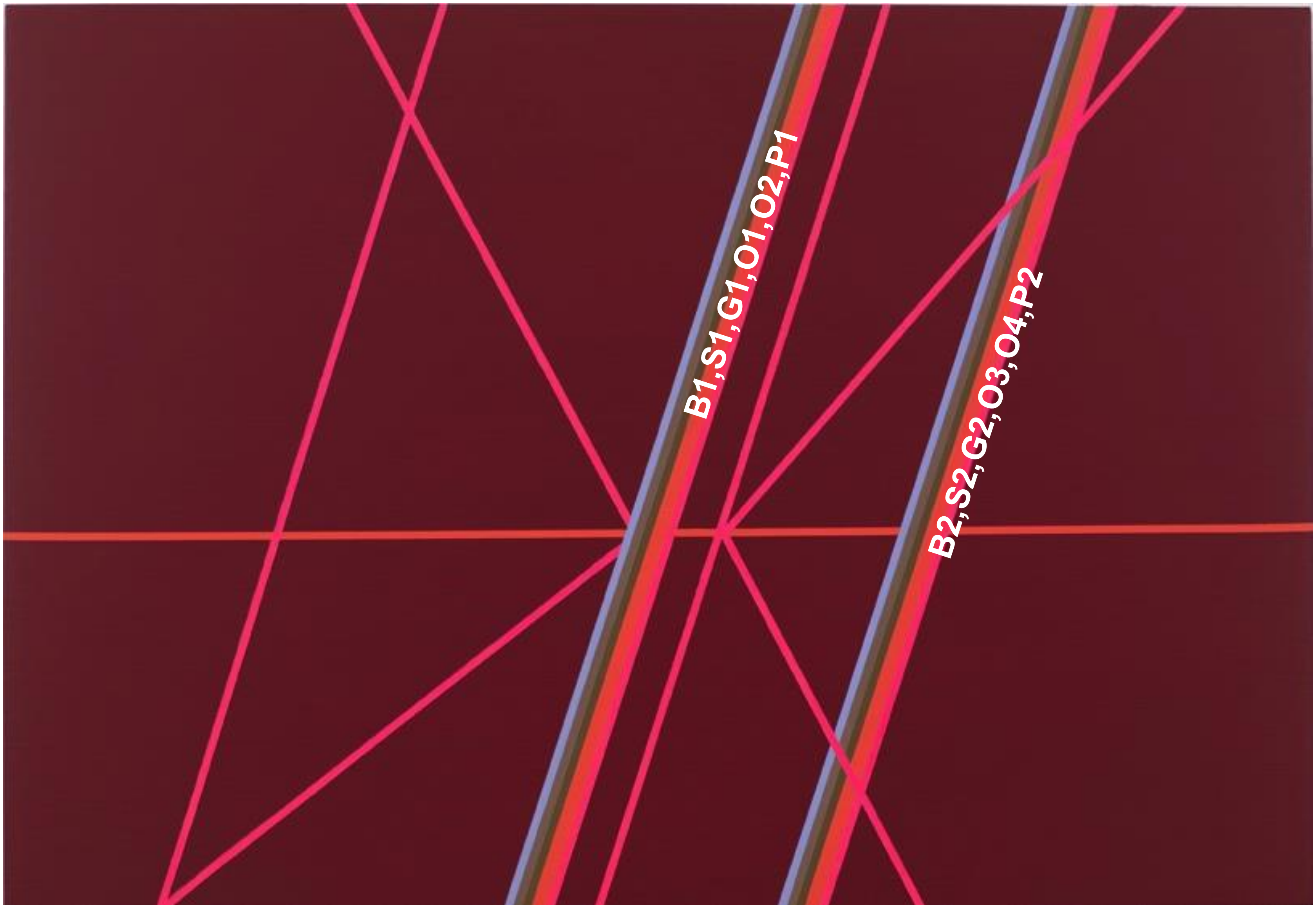



**Artist: Ann Pibal; Painting: "XCRS"**

# 1 Isolated Standard Edge

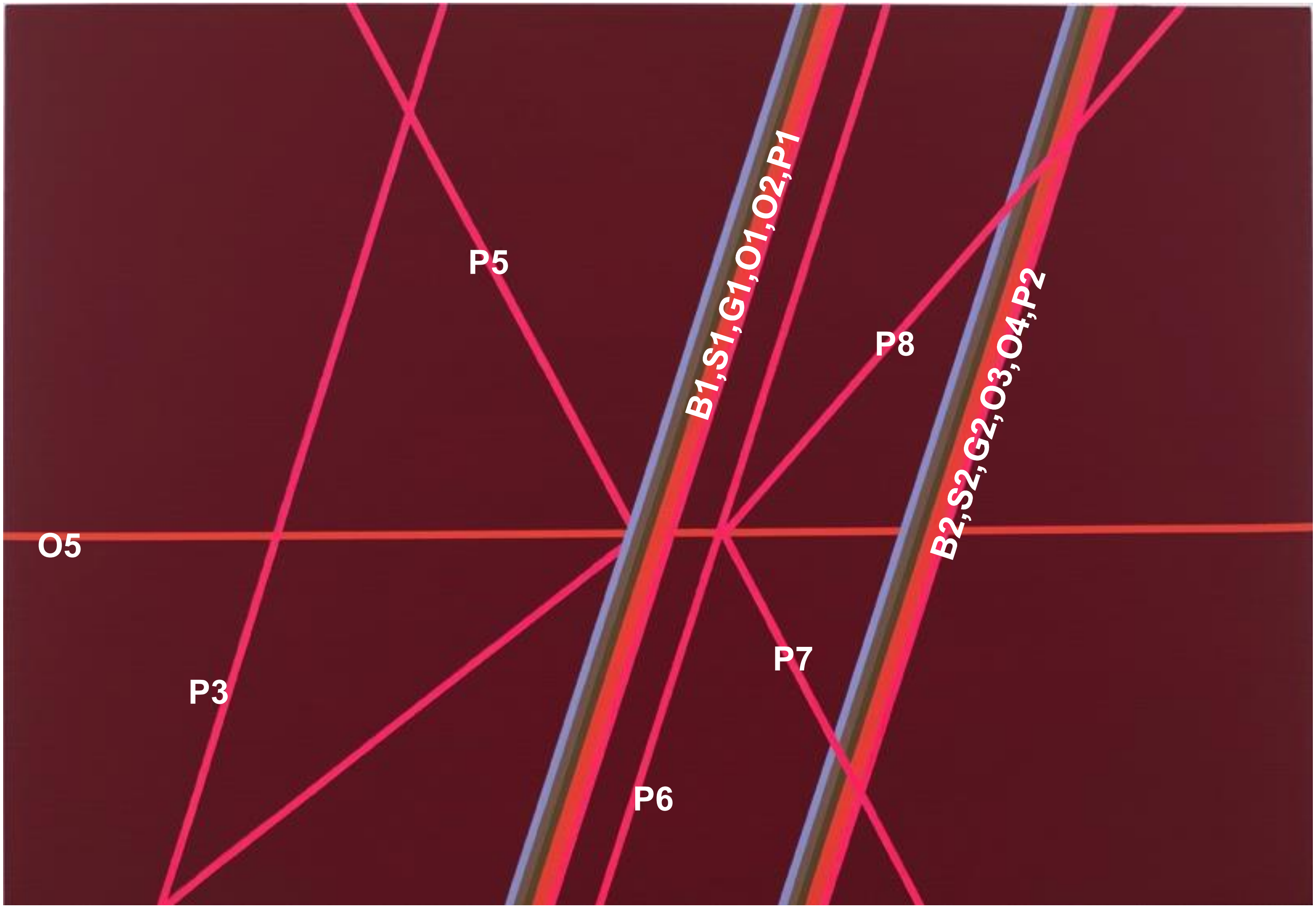

**Artist: Ann Pibal; Painting: "XCRS"**

# 12 Multi Edges



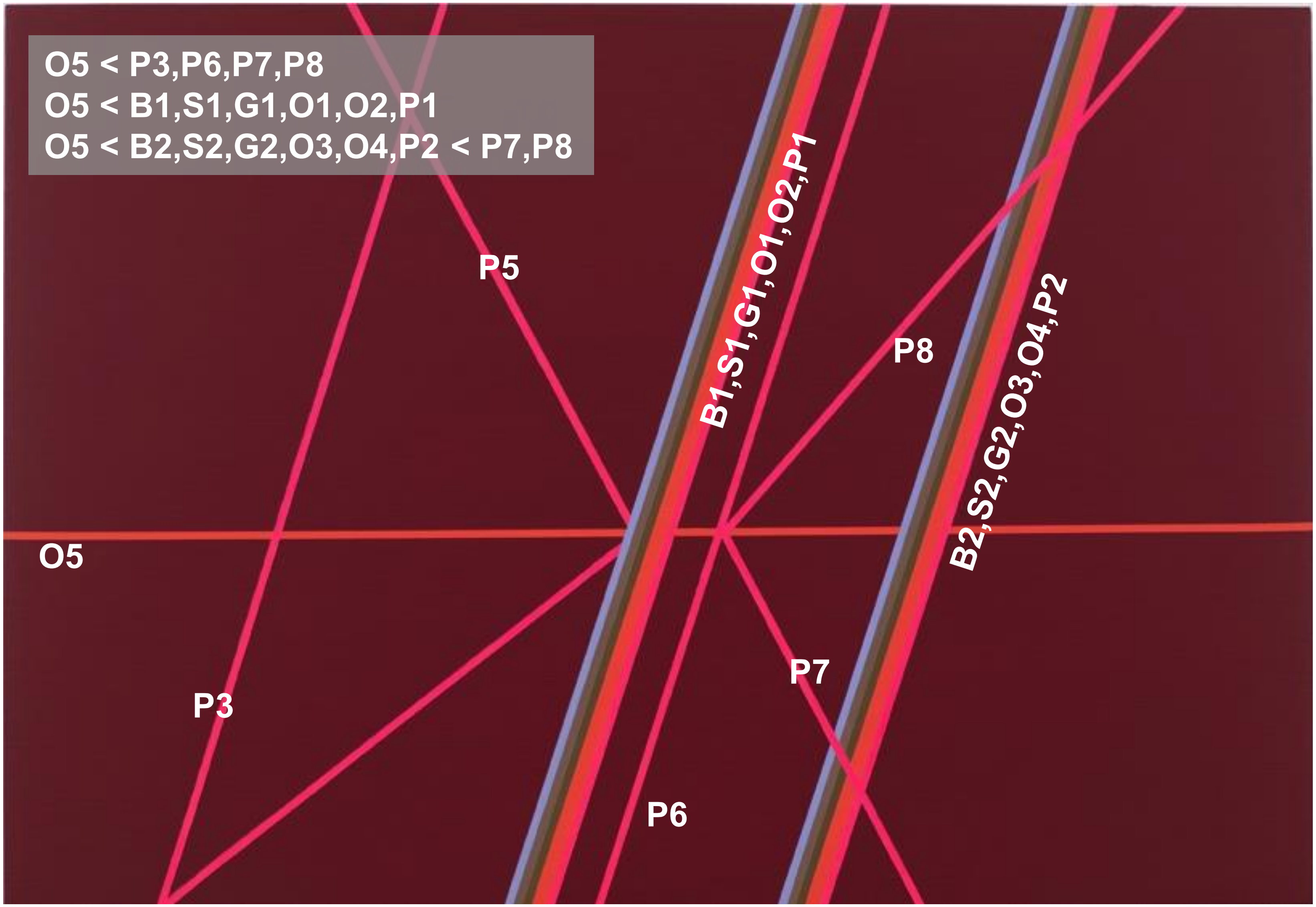

**Artist: Ann Pibal; Painting: “XCRS”**

# 18 Hyper Edges



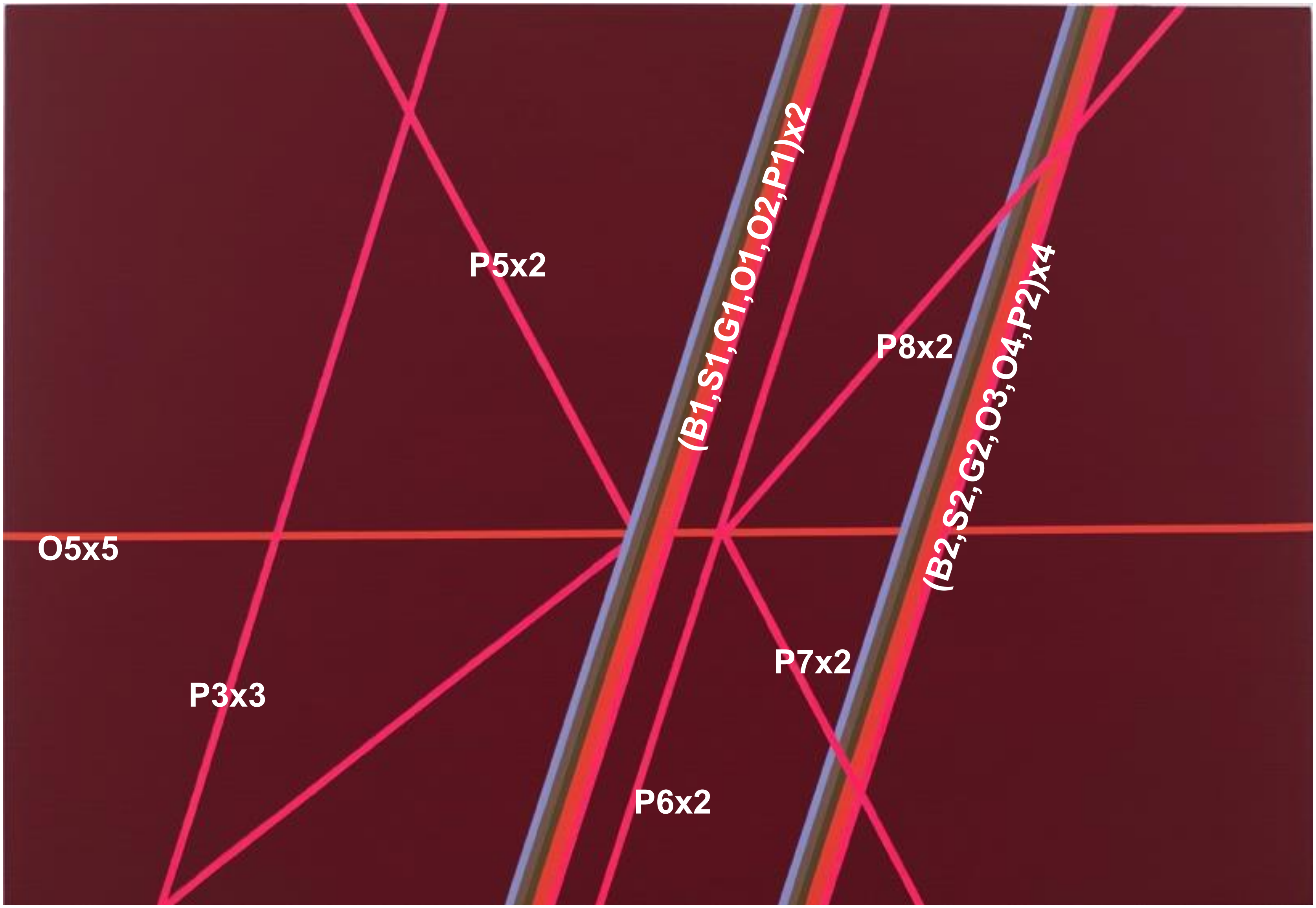

**Artist: Ann Pibal; Painting: "XCRS"**

# 27 Edge Orderings




**Artist: Ann Pibal; Painting: “XCRS”**

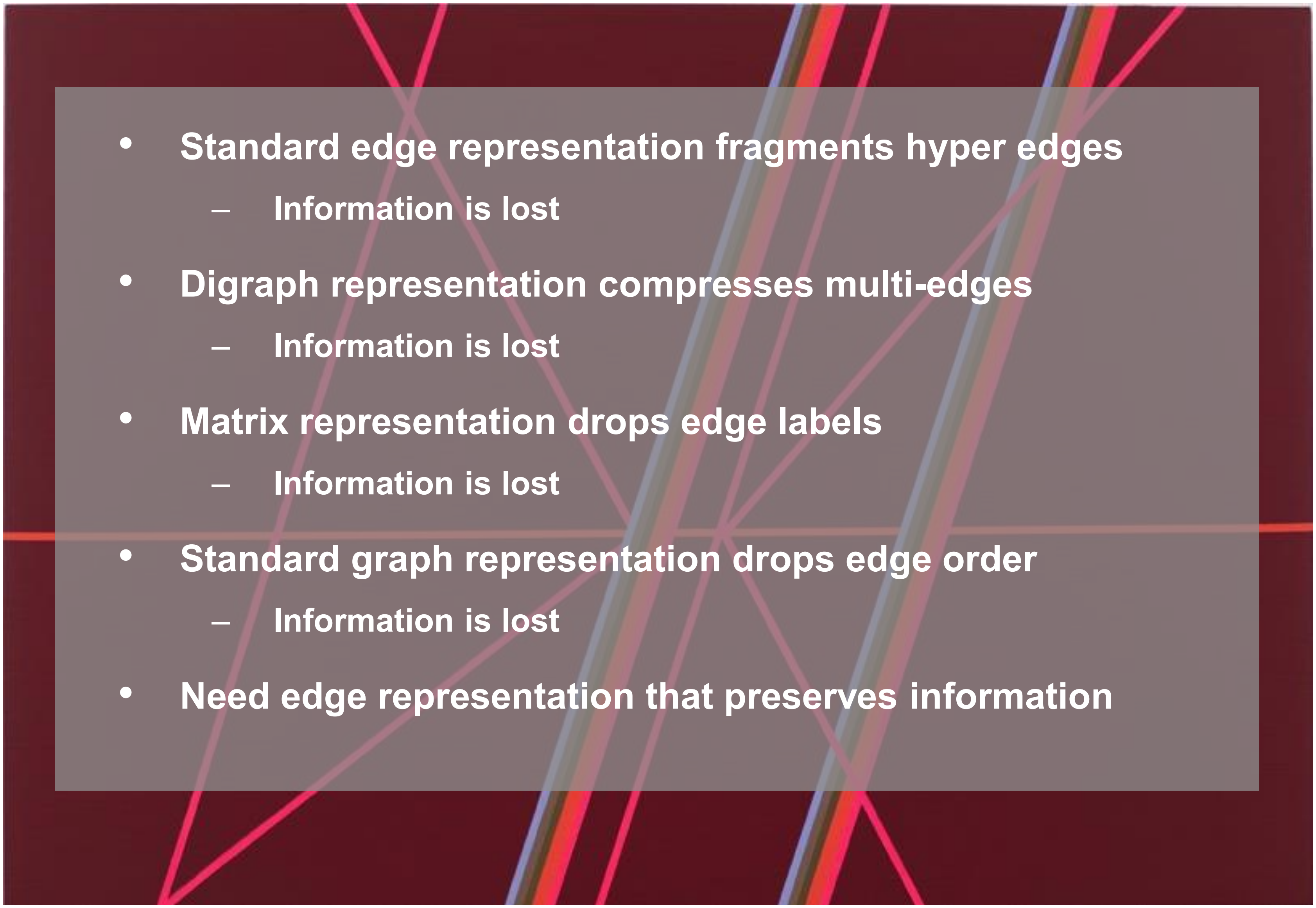
# 52 Standard Multi Edges




**Artist: Ann Pibal; Painting: "XCRS"**

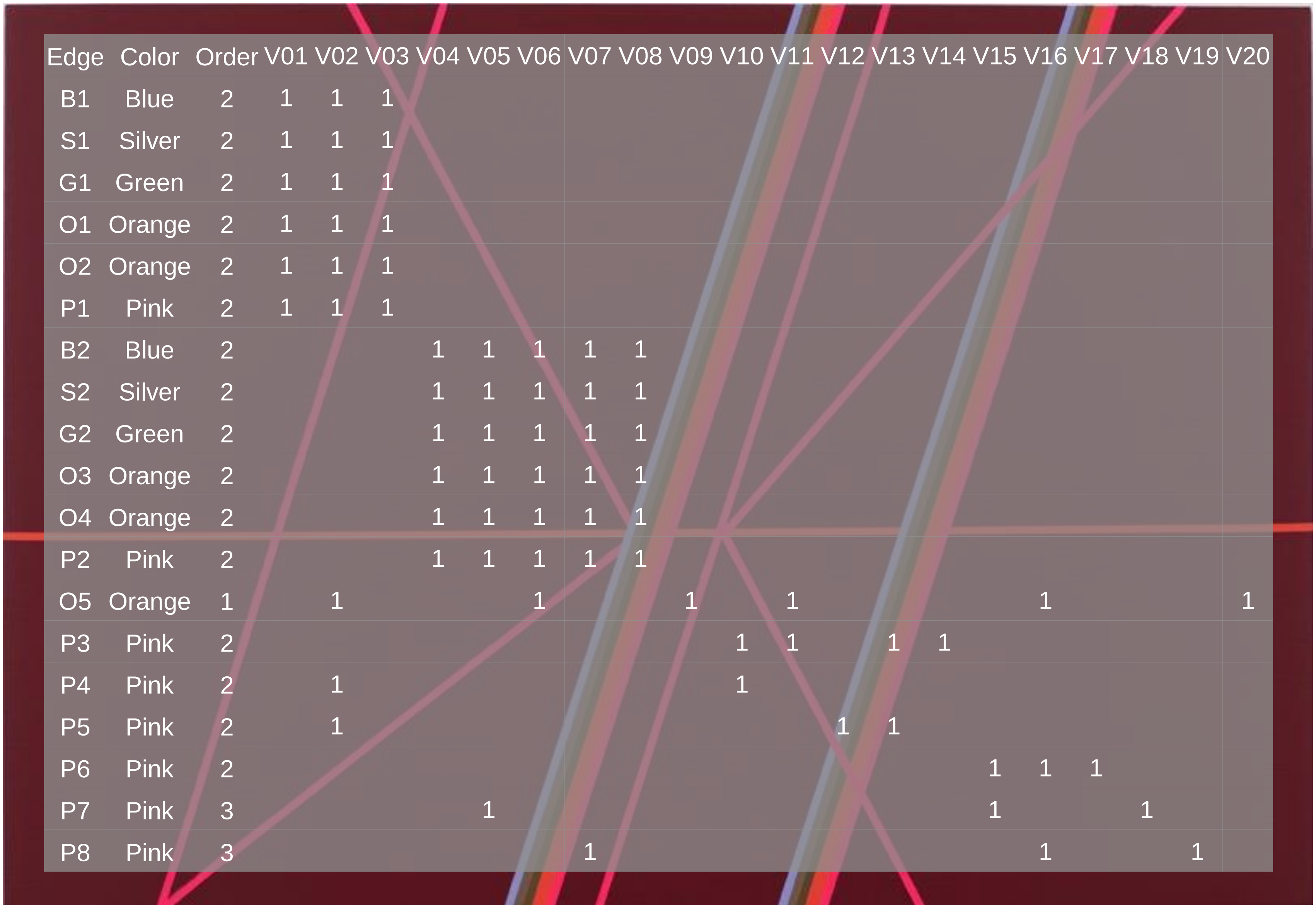
# Summary Observations

- Standard edge representation fragments hyper edges
  - Information is lost
- Digraph representation compresses multi-edges
  - Information is lost
- Matrix representation drops edge labels
  - Information is lost
- Standard graph representation drops edge order
  - Information is lost
- Need edge representation that preserves information



**Artist: Ann Pibal; Painting: “XCRS”**

# Solution: Incidence Matrix



| Edge | Color | Order | V01 | V02 | V03 | V04 | V05 | V06 | V07 | V08 | V09 | V10 | V11 | V12 | V13 | V14 | V15 | V16 | V17 | V18 | V19 | V20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| B1 | Blue | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| S1 | Silver | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| G1 | Green | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| O1 | Orange | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| O2 | Orange | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| P1 | Pink | 2 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | |
| B2 | Blue | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| S2 | Silver | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| G2 | Green | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| O3 | Orange | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| O4 | Orange | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| P2 | Pink | 2 | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | | | | |
| O5 | Orange | 1 | | 1 | | | | 1 | | | 1 | | 1 | | | | | 1 | | | | 1 |
| P3 | Pink | 2 | | | | | | | | | | 1 | 1 | | 1 | 1 | | | | | | |
| P4 | Pink | 2 | | 1 | | | | | | | | 1 | | | | | | | | | | |
| P5 | Pink | 2 | | 1 | | | | | | | | | | 1 | 1 | | | | | | | |
| P6 | Pink | 2 | | | | | | | | | | | | | | | 1 | 1 | 1 | | | |
| P7 | Pink | 3 | | | | | 1 | | | | | | | | | | 1 | | | 1 | | |
| P8 | Pink | 3 | | | | | | | 1 | | | | | | | | | 1 | | | 1 | |

**Artist: Ann Pibal; Painting: "XCRS"**

# Example Code & Assignment

- **Example Code**
  - **tools/d4m_api/examples/1Intro/2EdgeArt**
- **Assignment**
  - **Select a picture**
  - **Label the edges and vertices**
  - **Create the incidence matrix E**
  - **Compute adjacency matrix from the incidence matrix using the formula A=E'E**