

Evaluating Functional Group Detection in *Saccharomyces cerevisiae* Gene Networks through Dynamic Community Detection and Metric Optimization

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01

Overview of Biological Networks, Dynamic Community Detection, and Gene Co-Expression Networks

Overview of Biological Networks



Biological systems are inherently complex.

They involve numerous interacting components, such as genes, proteins, and metabolites, all working together to regulate life processes (Barabási and Oltvai, 2004).



They exhibit community structures.

These may pertain to functional modules which work to perform a biological role. It is an interesting area of research for analyzing how certain molecules are grouped within cells (Yu et al., 2013).

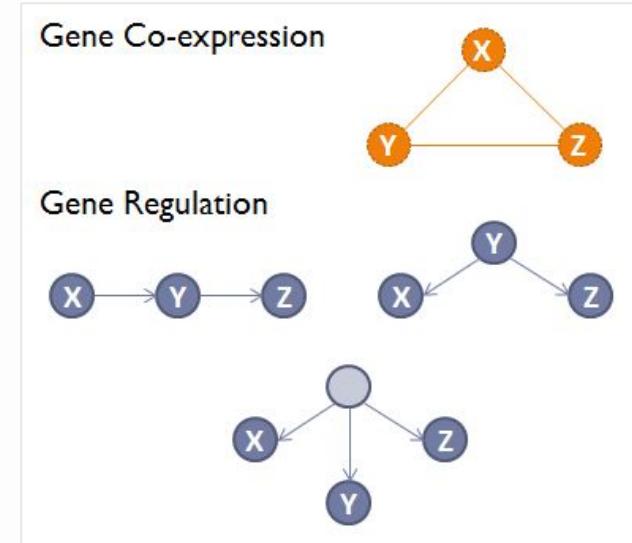


They are not static.

The dynamic nature is evident in gene co-expression networks. Studying the structure within these networks can provide insights on the regulation of biological functions and the interactions between genes.

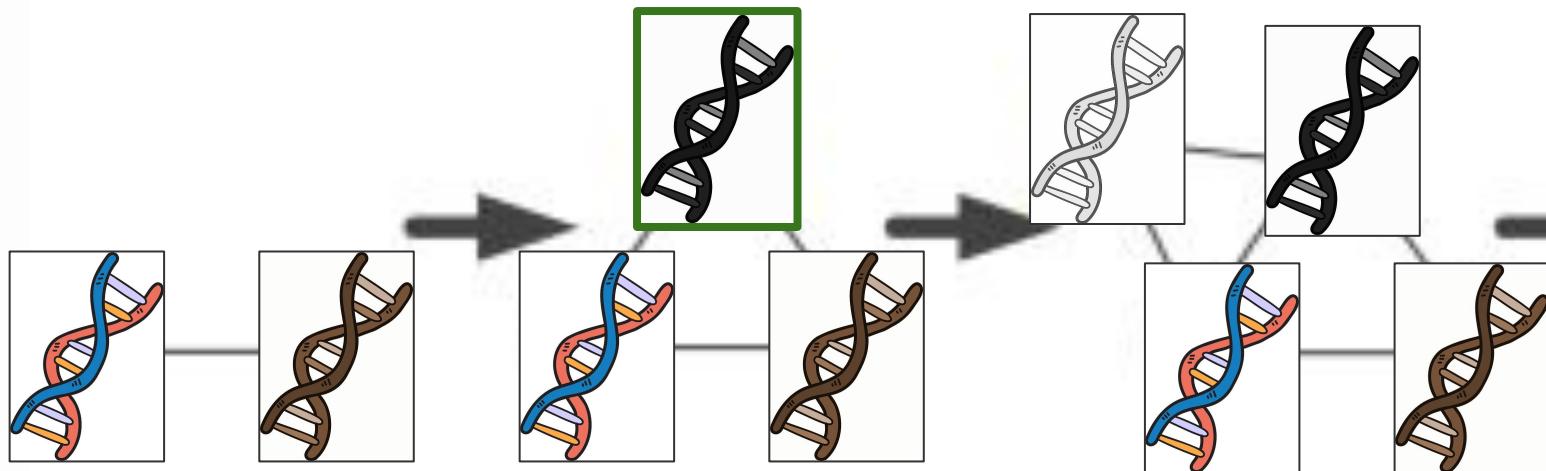
Gene Co-expression Networks

- Biological Network
- Nodes - Genes; Edges - Coexpression Relationship
 - A measure of similar patterns of activity (i.e. Expression Levels) across different conditions between genes.
 - If a pair of genes have their activity go up or down together, they are said to be coexpressed.
 - They must work together!



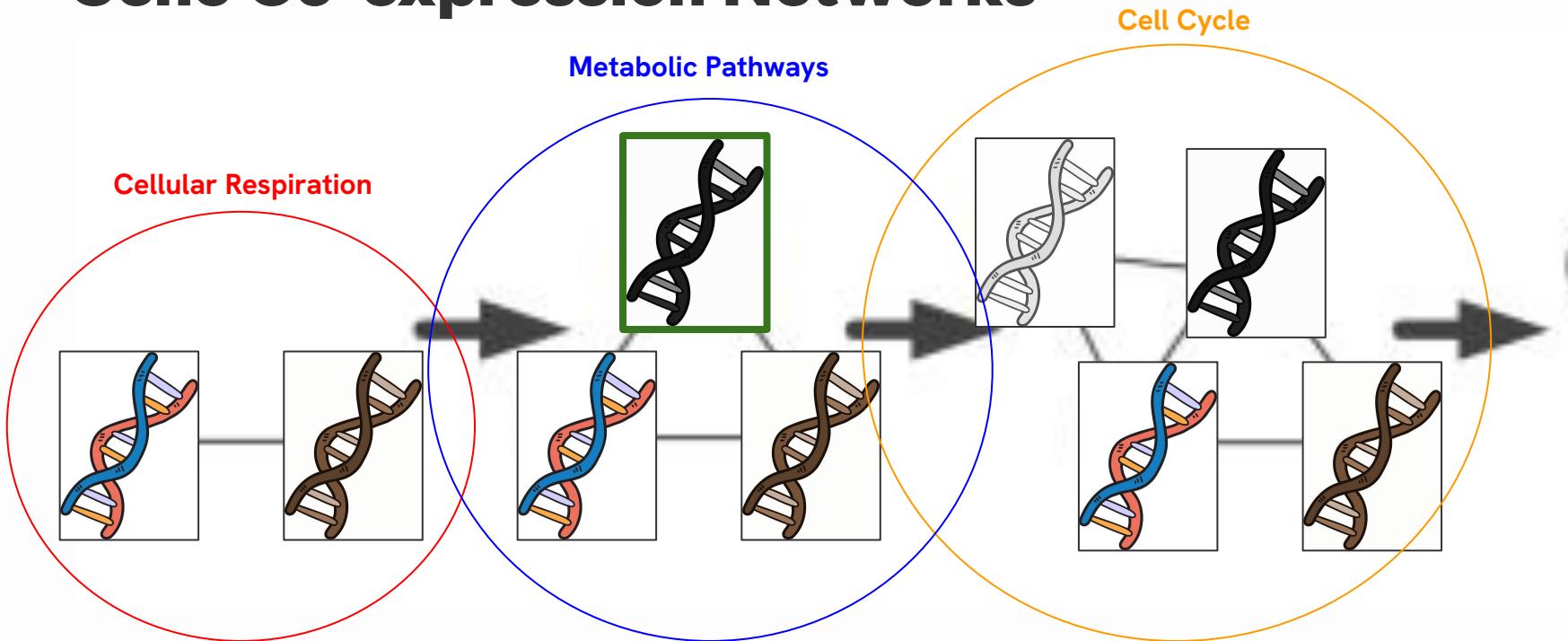
https://en.wikipedia.org/wiki/Gene_co-expression_network

Gene Co-expression Networks



Representing Gene Interactions as a Network!

Gene Co-expression Networks

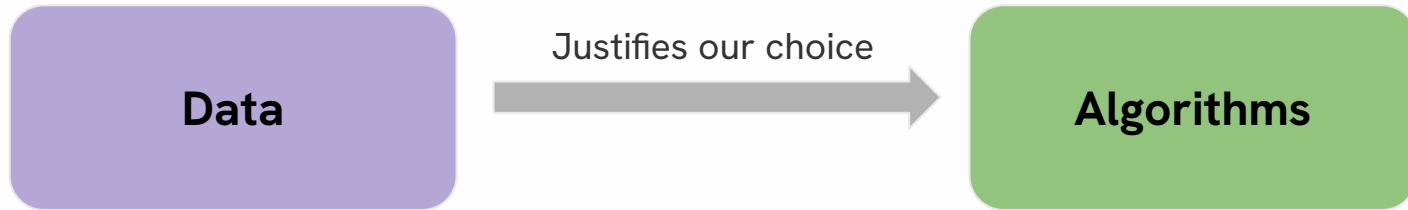


We Want to Detect Communities in Gene Networks!

Review of Related Literature

- Time-Series Gene Expression Data of *S. cerevisiae*
- Hierarchical Community Detection and the ARI
Agreement Measure in Gene Co-expression Networks
- Other DCD Algorithms
- Evaluation metrics (internal and external)

Review of Related Literature



What's the nature of our data?

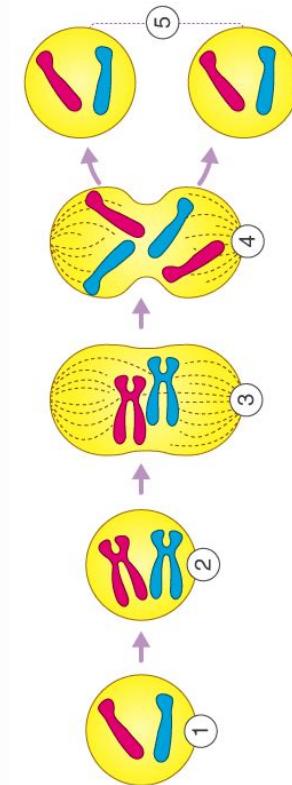
What past studies did they do
with our data?

Why is this algorithm
appropriate for our data?

How can we improve the
results given the same data?

Saccharomyces cerevisiae

- Well documented yeast cells, 6000 genes
- Dataset from Cho et al (1998)
 - Genes across the different phases of the mitotic cell cycle
 - Time-series data of gene expression
 - How do the gene networks change at different time points?

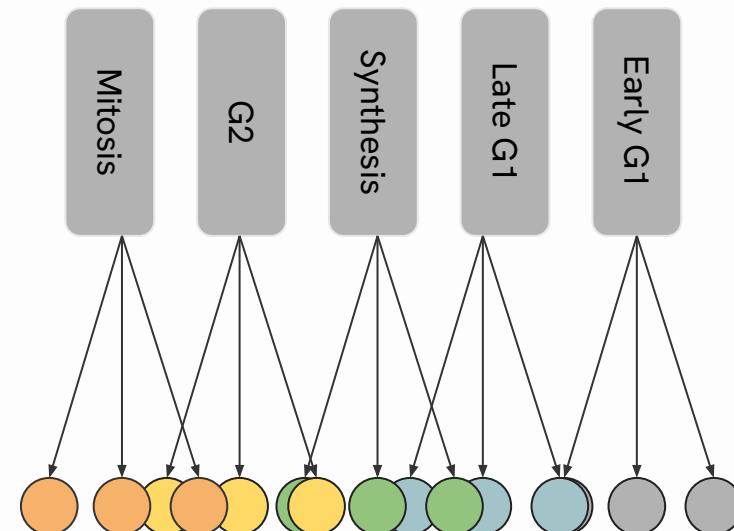
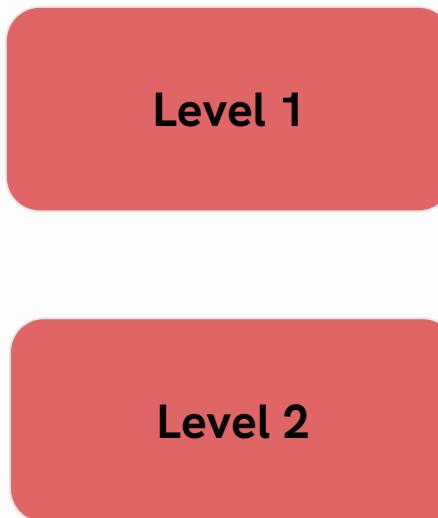


1 Interphase | 2 Prophase | 3 Metaphase | 4 Anaphase | 5 Telophase

Time-Series Gene Expression Data of *S. cerevisiae*

- Cho et al. (1998)
 - *S. cerevisiae* across different phases of the mitotic cell cycle.
 - 416 genes, **17 different time points**
 - This shows its dynamic nature!
 - Classify genes according to activity:
 1. Early G1 Phase
 2. Late G1 Phase
 3. Synthesis Phase
 4. G2 Phase
 5. Mitosis
 6. Multi-phase

Time-Series Gene Expression Data of S. *Cho Cerevisiae Dataset Structure*



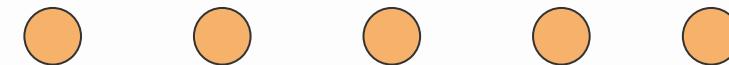
Time-Series Gene Expression Data of *S. cerevisiae*

- Yeung et al. (2001)
 - Reduced down to 384 genes, still 17 different time points
 - Removed Multi-phase
- Calderon et al. (2024)
 - Update Cho dataset, reconcile with the more modern Kyoto Encyclopedia of Genes and Genomes (KEGG).
 - Check agreement between Cho (2 Levels) and KEGG (3 Levels)

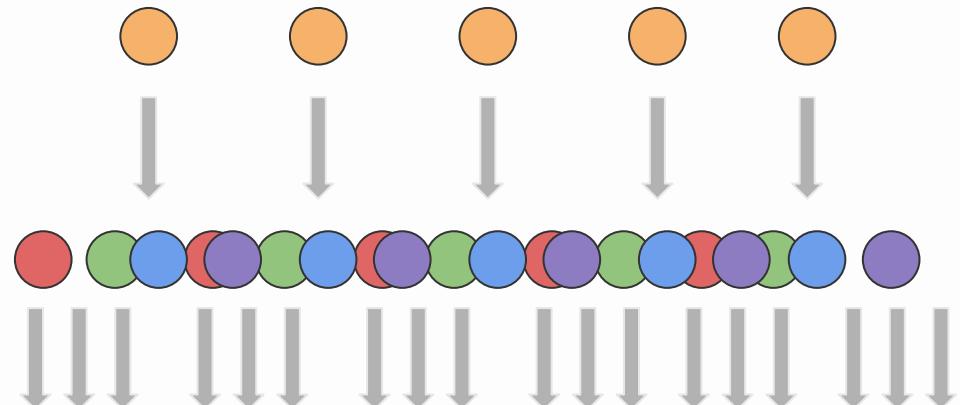
Time-Series Gene Expression Data of S. cerevisiae

KEGG Dataset Structure

Level 1



Level 2

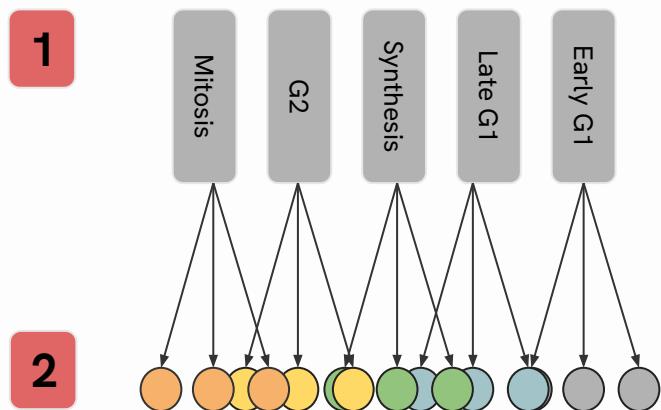


Level 3

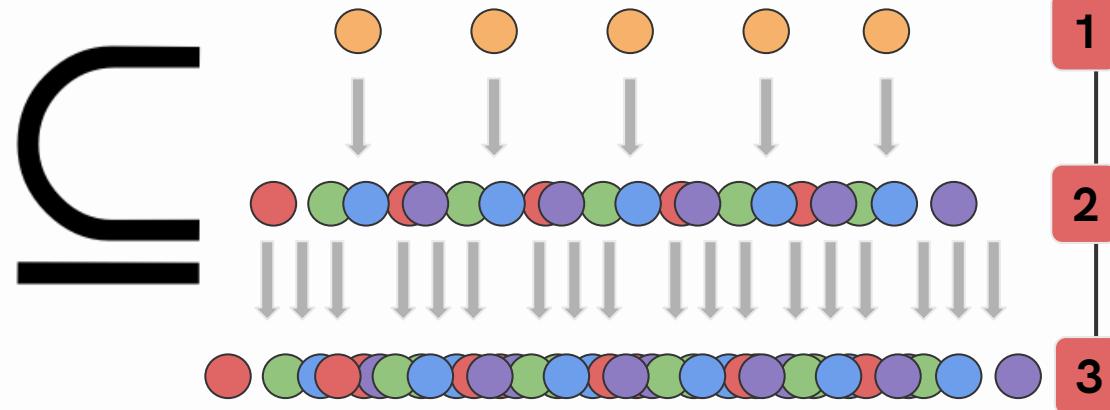


Time-Series Gene Expression Data of S. cerevisiae

Cho Dataset Structure



KEGG Dataset Structure



Time-Series Gene Expression Data of S. cerevisiae

- Calderon et al. (2024)
 - Use Adjusted Rand Index (ARI) to see how well Cho and KEGG “agree”

KEGG Level	CHO Level	ARI
1	1	0.022699
1	2	0.083272
2	1	0.057357
2	2	0.118445
3	1	0.043423
3	2	0.156492

ARI should be at least 0.5 to be relevant!

Community Detection Algorithms

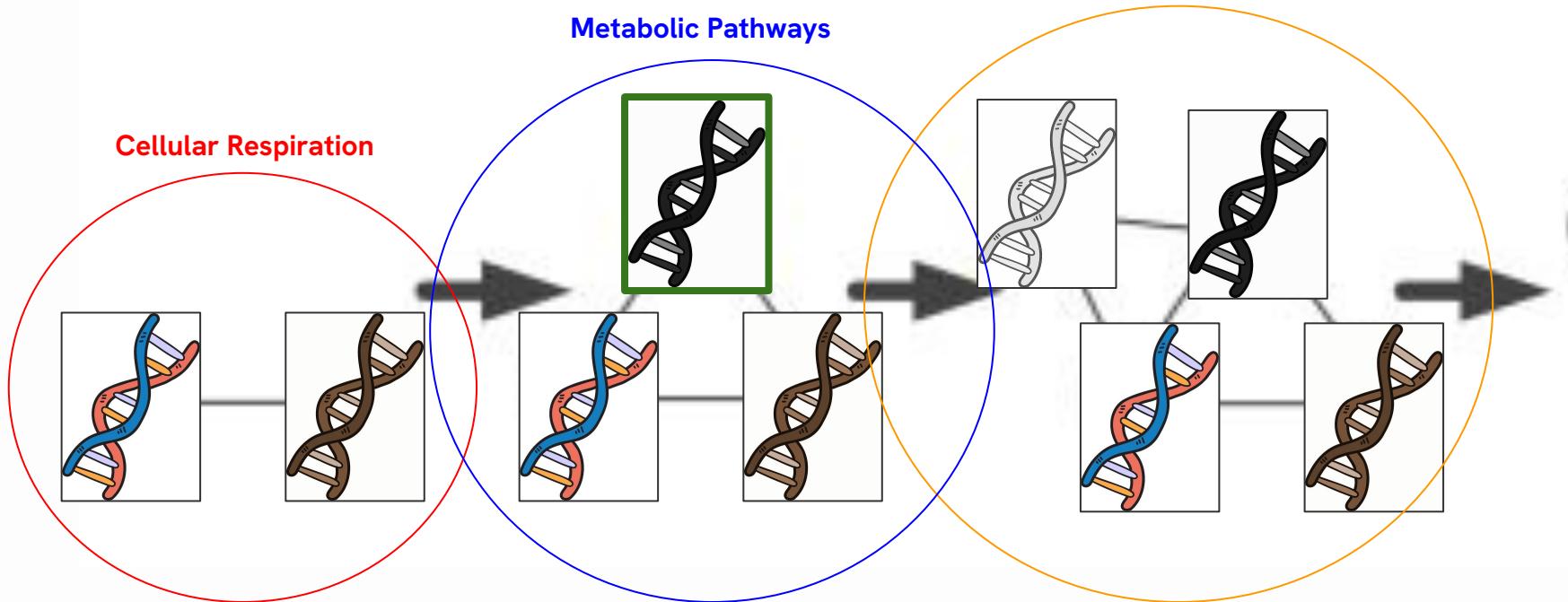
- NP-Hard
 - Combinatorial explosion; how many partitions could we make given a graph of n nodes? **Bell Numbers.**
 - Count the possible partitions in a set
 - For large n , Bell Numbers > Exponential
- Two categorizations
 - Static
 - Dynamic

Hierarchical Community Detection and ARI in GCN

- Calderon et al. (2024)
 - Use hierarchical community detection (HCD) in GCN of *S. cerevisiae*
 - Identify functional gene communities
 - Use three HCDs:
 - Girvan-Newman
 - Paris
 - Local Optimization Function Model

The Essence of Detecting Communities...

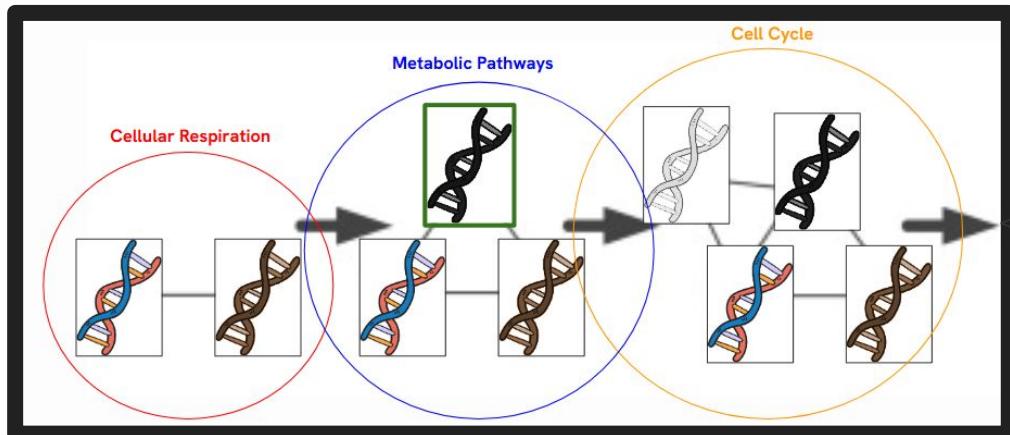
Cell Cycle



These Communities Mean a Biological Function!

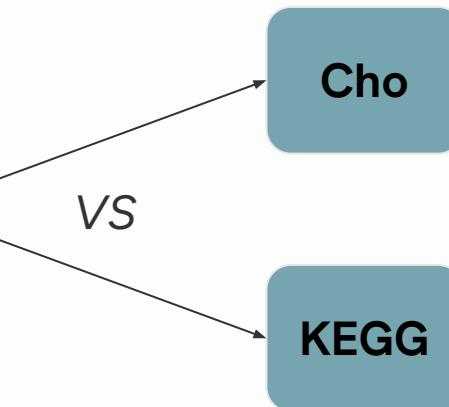
How To Test the Accuracy?

“Predicted” Communities



a.k.a Detected Functional Groupings

Actual Functional Groupings



Hierarchical Community Detection and ARI in GCN

- Calderon et al. (2024)
 - Use ARI (again!) to evaluate the agreement of detected gene communities (formed by HCD) with Cho and KEGG data.
 - Result: Relatively Low ARI scores across all HCD algorithms, on both datasets
 - Implication: Either HCD or ARI cannot fully capture the GCN of *S. cerevisiae*!
 - We want to try and improve this with DCD, and a metric other than ARI.

Dynamic Community Detection

Algorithms

- TILES Algorithm
 - Detects and tracks the evolution of overlapping communities
 - “Domino tile” approach



Dynamic Community Detection Algorithms

- TILES Algorithm

- Two types of community memberships
 - Core
 - Part of a triangle within the same community
 - Peripheral
 - Connected to a core node but not part of any triangle within the core node's community
- Only core nodes are allowed to propagate community membership.



Dynamic Community Detection

Algorithms

- TILES Algorithm
 - Generates overlapping communities, which is identical to real-world networks
 - Advantageous online nature
 - Localized updating process which involves few nodes and communities
 - Parallel execution, which supports faster community computations, and captures evolutionary behaviors



Dynamic Community Detection Algorithms

- TILES Algorithm

- Rossetti et al. (2017) assessed TILES against various CD algorithms (DEMON, CFinder, and iLCD) on synthetic and real-world networks
 - Faster execution times
 - More accurate with ground-truth communities
 - Identified significant lifecycle events
- Showed potential in adapting to gene co-expression networks



Dynamic Community Detection

Algorithms

- InfoMap Algorithm
 - Utilizes a map equation to detect community structures
 - Community detection as a coding problem
 - Minimum Description Length (MDL)
 - Description length of a random walker is expressed by the map equation.
 - Good modular structure = small description length
 - Description length can be compressed if a random walker stays longer within a partition.

Dynamic Community Detection Algorithms

- InfoMap Algorithm

- Groups nodes through a collective process, each node a separate module
- Randomly selects nodes to combine → significant decrease in the map equation
- Previously formed modules are treated as nodes in the succeeding steps and the process is repeated until it is no longer possible to obtain a decrease in the map equation.
- Fundamental: utilization of flows
 - Robust as long as clusters flow well inside the graph
 - Fails otherwise if there is a lack of flow

Statistical Analysis (Internal Criteria)

- Assess clustering results without the use of external information (e.g. ground truth)
- Modularity
 - Quality of a network community structure
 - High modularity → denser intraconnections compared to interconnections
 - Evaluate the strength of algorithm in dividing a network into communities

Statistical Analysis (Internal Criteria)

- Closeness Centrality
 - Quantify the speed of transmission of information to a node from other nodes
 - Overall accessibility of a node and capability to obtain information rapidly

Statistical Analysis (External Criteria)

- Evaluate the similarity of results of algorithms against a ground truth generated by prior experiments
- Adjusted Rand Index (ARI)
 - First need to understand Rand Index (RI)
 - Pairwise comparison of nodes if they belong in the same community
 - Compare these pairs against another graph
 - Score = 1 → same community/different communities in both graphs
 - Otherwise, score = 0 → difference in community structure

Statistical Analysis (External Criteria)

- Adjusted Rand Index (ARI)
 - Otherwise, it gets a 0 which indicates a difference in the community structure.
 - Result of dividing the sum of scores of all node pairs and number of pairs is between 0 and 1
 - Directly proportional to similarity of two graphs' community structures

Statistical Analysis (External Criteria)

- Adjusted Rand Index (ARI)

$$Rand(A, B) = \frac{n_{00} + n_{11}}{n_{00} + n_{11} + n_{01} + n_{10}}$$

- n_{00} : node pairs in G that are in different communities in A and different communities in B
- n_{11} : node pairs in G that are in the same community in A and B
- n_{01} : node pairs in G that are in different communities in A, but same community in B
- n_{10} : node pairs in G that are in the same community in A, but different communities in B
- **Rand(A,B) = sum of agreeing pairs / total number of pairs**

Statistical Analysis (External Criteria)

- Adjusted Rand Index (ARI)

$$ARI = \frac{RI - ExpectedRI}{MaxRI - ExpectedRI}$$

- ARI is simply an extension of RI where chance is taken into account.
- A value of 1 indicates the identicality between predicted and actual clustering.
- A negative value indicates that the cluster agreement is lower than expected by chance.

Statistical Analysis (External Criteria)

- Normalized Mutual Information (NMI)
 - Confusion matrix N is defined
 - Rows → ground truth class labels
 - Columns → communities generated by a CD algorithm
 - N_{ij} → number of nodes with class label i that are in community j .

Statistical Analysis (External Criteria)

- Normalized Mutual Information (NMI)

$$\text{NMI}(A, C) = \frac{-2 \sum_{i=1}^{n_A} \sum_{j=1}^{n_C} N_{ij} \log \left(\frac{N_{ij} N}{N_{i\cdot} N_{\cdot j}} \right)}{\sum_{i=1}^{n_A} N_{i\cdot} \log \left(\frac{N_{i\cdot}}{N} \right) + \sum_{j=1}^{n_C} N_{\cdot j} \log \left(\frac{N_{\cdot j}}{N} \right)}$$

- A → ground truth partition; C → CD algorithm partition
- n_A → # of ground truth communities; n_C → # of communities detected by the CD algorithm
- $N_{i\cdot}$ → # of nodes with class label i ; $N_{\cdot j}$ → # of nodes in community j
- NMI is equal to 1 if the partitions are equal; 0 otherwise

03

Statement of the Problem and Objectives

Statement of the Problem

- Calderon et. al (2024) used HCD and ARI to evaluate the detected gene communities and known biological classifications.
- However, their analysis yielded weak agreement scores.
 - Hierarchical approach may not capture the full structure
 - OR there is a better metric other than ARI

*How can the detection of gene communities in *S. cerevisiae* be improved to achieve stronger agreement?*

Objectives of the Study

1. Evaluate Alternative Similarity Metrics for Improved Community Consistency
 - Design a new metric MRI based on RI. Perform initial tests on sample partitions.
2. Predict Functional Classifications
 - Construct the GCN. Perform Dynamic Community Detection with TILES and InfoMap algorithms.
3. Compare the Performance of Dynamic and Hierarchical Community Detection Algorithms
 - Compare our detected communities in (2) with the work of Calderon et. al. by using our ground truth datasets (KEGG, Cho). Use the MRI, RI.

03

Methodology

Limitations of the Rand Index (RI)

- Calderon, et. al (2024) utilized the Adjusted Rand Index (ARI) metric, which is the adjusted version of the Rand Index (RI).
- We inspect the formula of Rand Index according to Baker, et. al (2018).

Limitations of the Rand Index (RI)

- Given a network G of i nodes, let A and B be two partitions of G . Then A and B contains the set of communities on the alphabet of G .
- For example,

$$G = \{a, b, c, d, e, f\}$$

$$A = \{\{a, b\}, \{c, d, e\}, \{f\}\}$$

$$B = \{\{a, b, c\}, \{d, e, f\}\}$$

$$G = \{a, b, c, d, e, f\}$$

$$A = \{\{a, b\}, \{c, d, e\}, \{f\}\}$$

$$B = \{\{a, b, c\}, \{d, e, f\}\}$$

$$Rand(A, B) = \frac{n_{00} + n_{11}}{n_{00} + n_{11} + n_{01} + n_{10}}$$

- n_{00} : node pairs in G that are in different communities in A and different communities in B. (e.g. the node pair (a,e))
- n_{11} : node pairs in G that are in the same community in A and B. (e.g. the node pair (a,b)).
- n_{01} : node pairs in G that are in different communities in A, but same community in B. (e.g. the node pair (a, c)).
- n_{10} : node pairs in G that are in the same community in A, but different communities in B. (e.g. the node pair (c, d)).
- **Rand(A,B) = sum of agreeing pairs / total number of pairs**

$$G = \{a, b, c, d, e, f\}$$

$$A = \{\{a, b\}, \{c, d, e\}, \{f\}\}$$

$$B = \{\{a, b, c\}, \{d, e, f\}\}$$

(a,b)

(a,c)

(a,d)

(a,e)

(a,f)

(b,c)

(b,d)

(b,e)

(b,f)

(c,d)

(c,e)

(c,f)

(d,e)

(d,f)

(e,f)

n_{00}	n_{11}	n_{01}	n_{10}
(a,d)	(a,b)	(a,c)	(c,d)
(a,e)	(d,e)	(b,c)	(c,e)
(a,f)		(d,f)	
(b,d)		(e,f)	
(b,e)			
(b,f)			

$$\text{Rand}(A,B) = (7 + 2)/(7+2+4+2)$$

$$= 0.6 \text{ (slightly significant result)}$$

Limitations of the Rand Index (RI)

- Recall: Given a network G of i nodes, let A and B be two partitions of G . Then A and B contains the set of communities on the nodes of G .
- However this assumes that **A and B come from a singular data source**. That is, we have the same nodes.
- Which is not the case for our study where we have two datasets: Cho and KEGG.
 - Cho contains fewer genes than KEGG. They have **different nodes**.
- For example:
 - Assume A is derived from Cho and B is derived from KEGG.

$$A = \{\{a, b, g\}, \{c, d, e\}, \{f\}\}$$

$$B = \{\{a, b, c, x\}, \{d, e, f\}\}$$

$$Rand(A, B) = \frac{n_{00} + n_{11}}{n_{00} + n_{11} + n_{01} + n_{10}}$$

- Suppose we find all possible node pairs and classify them, as we usually do in computing the Rand Index. How then do we classify the node pair (a, x) ?
 - Well, it's in a community in B...
 - But how do we do so for A? The node x is not part of the alphabet of A.

$$A = \{\{a, b, g\}, \{c, d, e\}, \{f\}\}$$

$$B = \{\{a, b, c, x\}, \{d, e, f\}\}$$

(a,b)	(c,d)
(a,c)	(c,e)
(a,d)	(c,f)
(a,e)	(c,x)
(a,f)	
(a,x)	
	(d,e)
	(d,f)
(b,c)	(d,x)
(b,d)	
(b,e)	
(b,f)	(e,f)
(b,x)	(e,x)

$$Rand(A, B) = \frac{n_{00} + n_{11}}{n_{00} + n_{11} + n_{01} + n_{10}}$$

n_{00}	n_{11}	n_{01}	n_{10}	??
(a,d)	(a,b)	(a,c)	(c,d)	(a,x)
(a,e)	(d,e)	(b,c)	(c,e)	(b,x)
(a,f)	(a,f)	(d,f)		(c,x)
	(b,d)	(e,f)		(d,x)
	(b,e)			(e,x)
	(b,f)			
	(c,f)			

$$Rand(A, B) = ???$$

Designing the Modified Rand Index (MRI)

$$MRI(A, B) = \frac{n_{00} + n_{11} + n_{xx}}{n_{00} + n_{11} + n_{01} + n_{10} + n_{xx}}$$

- n_{xx} : the number of pairs where at least one node in the pair does not exist in one of the partitions, ensuring that pairs missing from either A or B are appropriately categorized.
- Test this new metric on some sample partitions

$$A = \{\{a, b, g\}, \{c, d, e\}, \{f\}\}$$

$$MRI(A, B) = \frac{n_{00} + n_{11} + n_{xx}}{n_{00} + n_{11} + n_{01} + n_{10} + n_{xx}}$$

$$B = \{\{a, b, c, x\}, \{d, e, f\}\}$$

(a,b)	(c,d)
(a,c)	(c,e)
(a,d)	(c,f)
(a,e)	(c,x)
(a,f)	
(a,x)	(d,e)
	(d,f)
(b,c)	(d,x)
(b,d)	
(b,e)	(e,f)
(b,f)	(e,x)
(b,x)	

n ₀₀	n ₁₁	n ₀₁	n ₁₀	n _{xx}
(a,d)	(a,b)	(a,c)	(c,d)	(a,x)
(a,e)	(d,e)	(b,c)	(c,e)	(b,x)
(a,f)		(d,f)		(c,x)
(b,d)		(e,f)		(d,x)
	(b,e)			(e,x)
	(b,f)			
	(c,f)			

$$\begin{aligned} \text{Rand}(A, B) &= (7 + 2 + 5)/20 \\ &= 0.7 \text{ (statistically significant)} \end{aligned}$$

Testing the Modified Rand Index (MRI)

$$MRI(A, B) = \frac{n_{00} + n_{11} + n_{xx}}{n_{00} + n_{11} + n_{01} + n_{10} + n_{xx}}$$

- **Ideal Case:** Generate two partitions with perfect agreement. MRI should yield a score of 100%.
- **General Case:** Generate two random partitions, reflecting real world scenarios.
- **Non-Ideal Case:** Generate two partitions with drastically varying levels of disagreement.

Dynamic Community Detection (Forming the GCN)

- We first define the structural properties of the GCN to ensure its compatibility with DCD algorithms.
- Edge-Weighted and Undirected
 - Relationships between genes using weighted edges based on their co-expression values
- Temporal Representation
 - Modeled dynamically across different time points to capture changes in co-expression relationships over time
- Using the above properties, we form the GCNs for both the Cho and KEGG datasets through a **value-based algorithm** for network construction

Dynamic Community Detection (Forming the GCN)

• Correlation-Based Edge Weights

- Pearson Correlation Coefficient (PCC) is used to quantify pairwise gene co-expression relationships and to measure the linear relationship between gene expression profiles across time.
- Thresholding Correlation Values
 - A threshold value ($\delta = 0.85$) is applied to determine whether an edge between two genes exists. An edge is only created when it exceeds this threshold, ensuring that only strongly co-expressed genes are connected.

Dynamic Community Detection (Forming the GCN)

- Forming GCNs for Cho and KEGG

- Networks are weighted and undirected to reflect mutual interactions between genes.
- Same construction method for both datasets ensures consistency, facilitating comparisons between the networks and their detected communities.

Dynamic Community Detection (Applying)

- Identify and implement DCD algorithms for *weighted* and *undirected* networks
- InfoMap
 - Algorithm that utilizes a map equation to detect community structures in networks and employs the concept of minimum description length in optimally computing partitions
- TILES
 - Algorithm that is able to detect and track evolution of overlapping communities in dynamic networks, similar to the fall of a domino tile

Performance Comparison of Hierarchical and Dynamic

- Determine which algorithms are suitable for deriving biologically significant results
- Internal Criteria (all are available from the NetworkX library)
 - Modularity
 - Quality of a network's community structure
 - High modularity indicates denser connections between vertices in the same community compared to vertices in different communities
 - Closeness Centrality
 - Transmission rate of information to a node from all other nodes
 - Accessibility and ability to quickly capture information

Performance Comparison of Hierarchical and Dynamic

- External Criteria (the following are available from the Scikit-learn library)

- Rand Index (ARI)
 - Similarity between two communities
 - Considers all node pairs and determines whether they belong in the same community
 - Probability that a node pair from A and B will agree
- Normalized Mutual Information
 - Quality of clustering results compared to ground truth
 - Result is 1 if identical; 0 otherwise

Performance Comparison of Hierarchical and Dynamic

External Criteria

- Modified Rand Index (MRI)
 - Addresses a significant weakness of RI by accounting for pairs that involve nodes that are missing in one of the two networks being compared
 - Might yield stronger RI scores

04

Scope and Limitations of the Study

Scope and Limitations of the Study

- Primarily focused on dynamic community detection and modification of the Rand Index (RI) formula
- Same dataset as the one used by Calderon et al. (2024)
 - 384 genes
- Utilize only existing DCD algorithms that are proven effective in biological contexts
- Cannot directly compare our proposed metric MRI to ARI
- Employ both existing scoring metrics and proposed metric (MRI) in assessing the performance of DCD algorithms

05

Timeline of Activities

Timeline of Activities

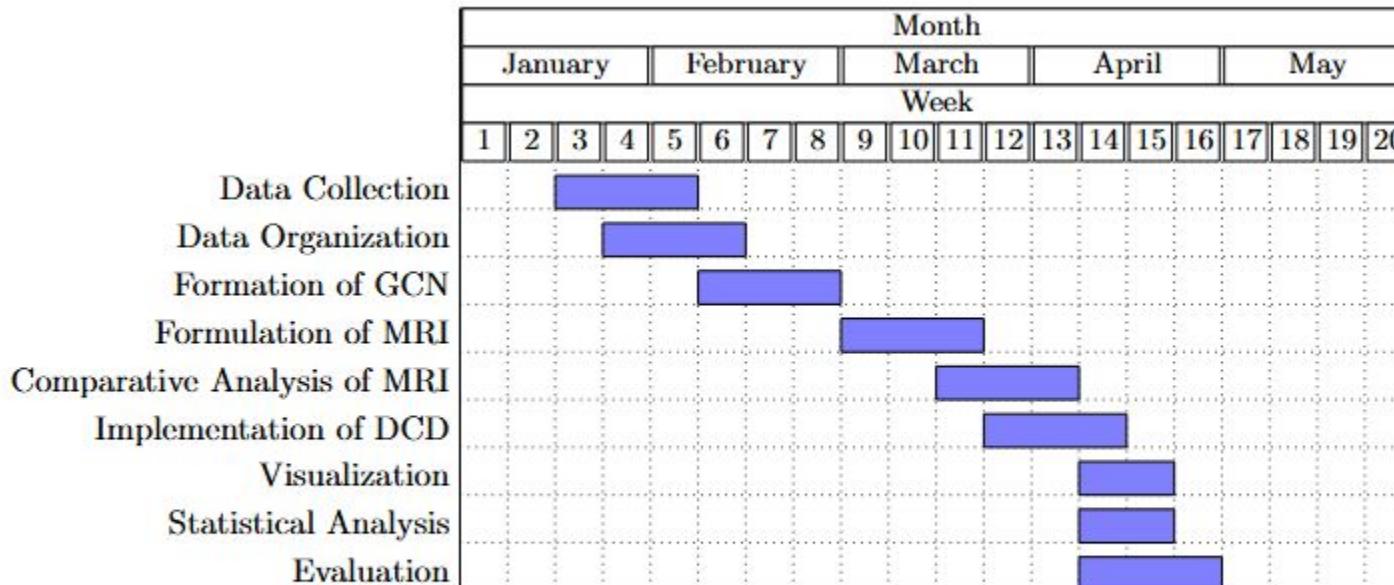


Fig. 1. Timeline for Methodology

06

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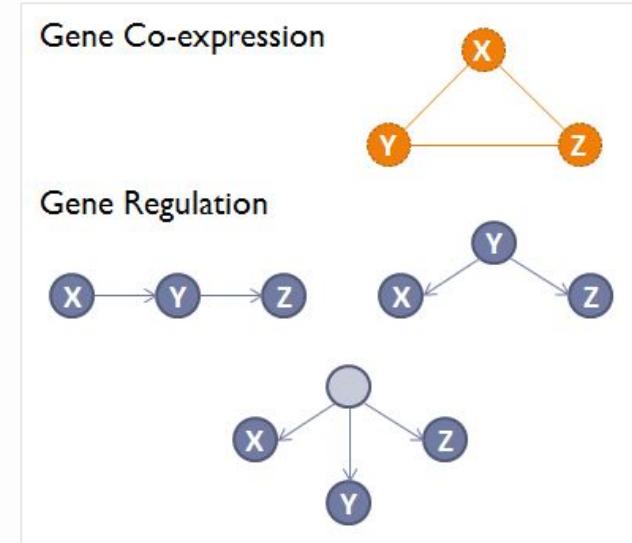
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Gene Co-expression Networks

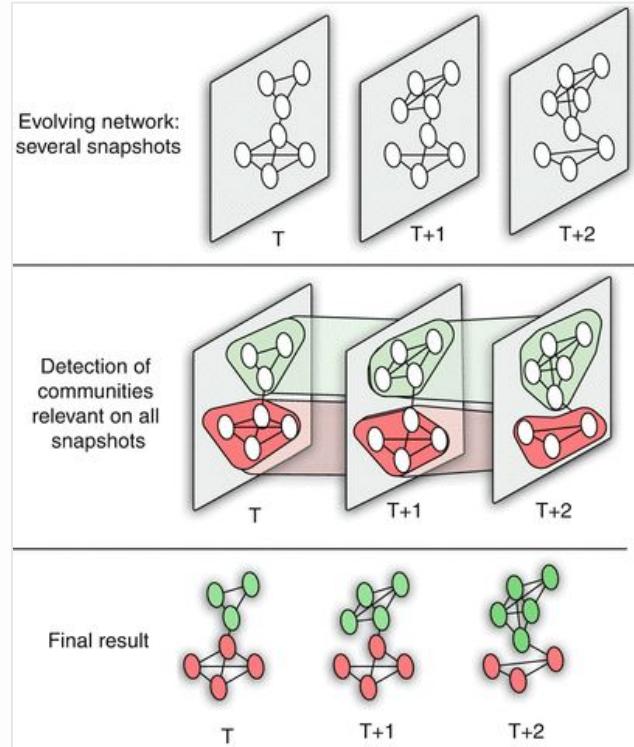
- Biological Network
- Nodes - Genes; Edges - Coexpression Relationship
 - A measure of similar patterns of activity (i.e. Expression Levels) across different conditions between genes.
 - If a pair of genes have their activity go up or down together, they are said to be coexpressed.
 - They must work together!



https://en.wikipedia.org/wiki/Gene_co-expression_network

Community Detection

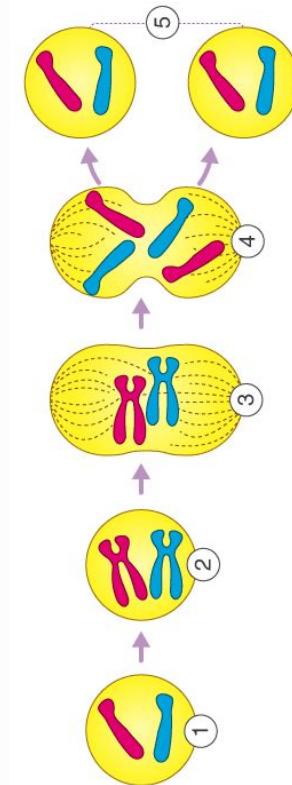
- Static Community Detection
 - Assumes the network is fixed throughout different time periods
 - Can reveal hierarchies in networks
- Dynamic Community Detection
 - Detect how communities vary at each time step
 - Can reveal temporal patterns
 - Our method of interest



https://link.springer.com/referenceworkentry/10.1007/978-1-4614-6170-8_383

Saccharomyces cerevisiae

- Well documented yeast cells, 6000 genes
- Dataset from Cho et al (1998)
 - Genes across the different phases of the mitotic cell cycle
 - Time-series data of gene expression
 - How do the gene networks change at different time points?



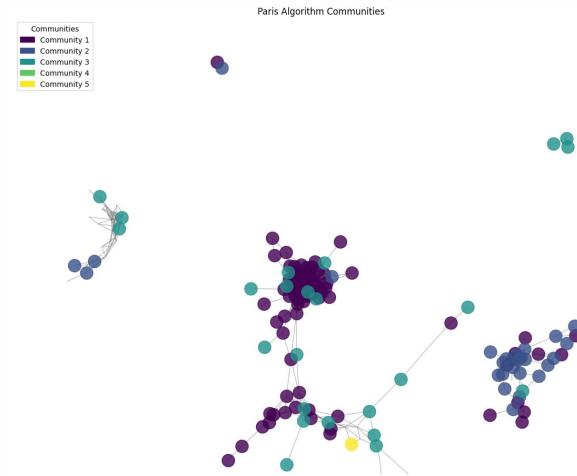
1 Interphase | 2 Prophase | 3 Metaphase | 4 Anaphase | 5 Telophase

03

Related Works

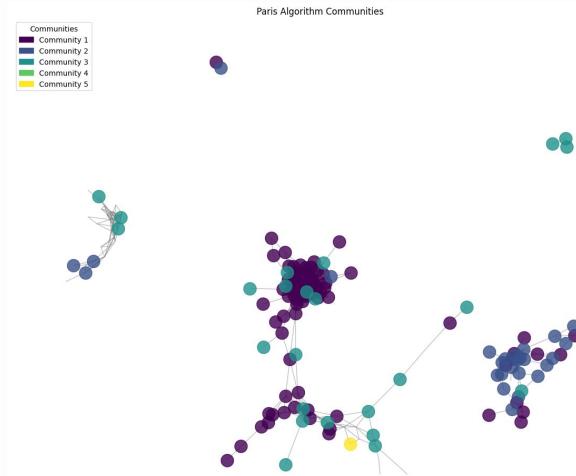
Hierarchical CD on GCNs

- Calderon and Ventures (2024)
 - Explored hierarchical CD in *S. cerevisiae* to enhance functional classification of cell-cycle regulated genes
 - Analyzed the performance of three algorithms:
 - Girvan-Newman
 - Paris
 - LFM



Hierarchical CD on GCNs

- Calderon and Ventures (2024)
 - Hierarchical CD is appropriate for GCNs due to their hierarchical nature.
 - Valuable insights into the static structure of GCNs
 - Open problem: dynamic nature of gene interactions



Dynamic Community Detection Algorithms

- C-Blondel Algorithm
 - Proposed by Seifkar et al. (2020)
 - Built upon the Louvain algorithm, and leverages historical information to improve execution time
 - Compresses the network into supernodes and superedges
 - Identifies **destructive nodes** through a degree centrality heuristic
 - Faster than other DCD algorithms (D-Blondel, S-Blondel)
 - Comparable performance in terms of modularity

Dynamic Community Detection Algorithms

- Semi-supervised ENMF (sE-NMF) Algorithm
 - Proposed by Ma and Dong (2017)
 - Combines evolutionary nonnegative matrix factorization (ENMF) and spectral clustering for dynamic community detection, balancing clustering accuracy and temporal consistency
 - Key advantage: Leveraging **a priori information**, avoiding local optima without affecting the run time complexity

Dynamic Community Detection

Algorithms

- Semi-supervised ENMF (sE-NMF) Algorithm
 - Evaluated against three well-known DCD algorithms (FacetNet, Kim-Han, DYNMOGA)
 - Particularly interesting network: breast cancer progression based on gene expression data
 - Outperformed the other algorithms in terms of specificity and sensitivity
 - Great potential as a tool for assessing temporal networks of disease progression

Thanks!

Do you have any questions?

Carmelo Ellezandro Atienza | Calvin James Maximo
craatienza1@up.edu.ph | ctmaximo1@up.edu.ph

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Outline

- An Overview of Biological Networks
- An Overview of Community Detection
- Gene Co-expression Networks
- Review of Related Literature
 - Hierarchical Community Detection by Ventures, Calderon
 - Dynamic Community Detection Algorithms

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Table of contents

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06

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Current situation & problems statement

Current situation

Jupiter is a gas giant and the biggest planet in the Solar System. It's the fourth-brightest object in the night sky. It was named after the Roman god of the skies and lightning



01



02



03

Earth

Earth is the third planet from the Sun and has life

Mars

Despite being red, Mars is actually a cold place

Mercury

Mercury is the smallest planet in the Solar System

Problems

Hypotheses



Hypothesis 1

Mercury is the closest planet to the Sun. The planet's name has nothing to do with the liquid metal



Hypothesis 2

Venus has a beautiful name and is the second planet from the Sun. It's hot and its atmosphere is poisonous



Hypothesis 3

Jupiter is a gas giant and the biggest planet in the Solar System. It was named after the Roman god

Study objectives



Mercury

Mercury is the closest planet to the Sun and the smallest of them all



Venus

Venus has a beautiful name and is the second planet from the Sun



Mars

Despite being red, Mars is actually a cold place. It's full of iron oxide dust

Reviewing concepts is a good idea



Mars

Mars is actually a very cold place



Venus

Venus has extremely high temperatures



Neptune

Neptune is the farthest planet from the Sun



Mercury

Mercury is the closest planet to the Sun



Saturn

Saturn is a gas giant with several rings



Jupiter

Jupiter is the biggest planet of them all

Literature review

- AUTHOR. (YEAR). *Title of the publication*. Publisher
 - Mercury is the closest planet to the Sun and the smallest one
- AUTHOR. (YEAR). *Title of the publication*. Publisher
 - Mars is full of iron oxide dust, which gives the planet its reddish cast
- AUTHOR. (YEAR). *Title of the publication*. Publisher
 - Jupiter is a gas giant and the biggest planet in the Solar System
- AUTHOR. (YEAR). *Title of the publication*. Publisher
 - Venus has a beautiful name and is the second planet from the Sun
- AUTHOR. (YEAR). *Title of the publication*. Publisher
 - Earth is the third planet from the Sun and harbors life

Theoretical framework

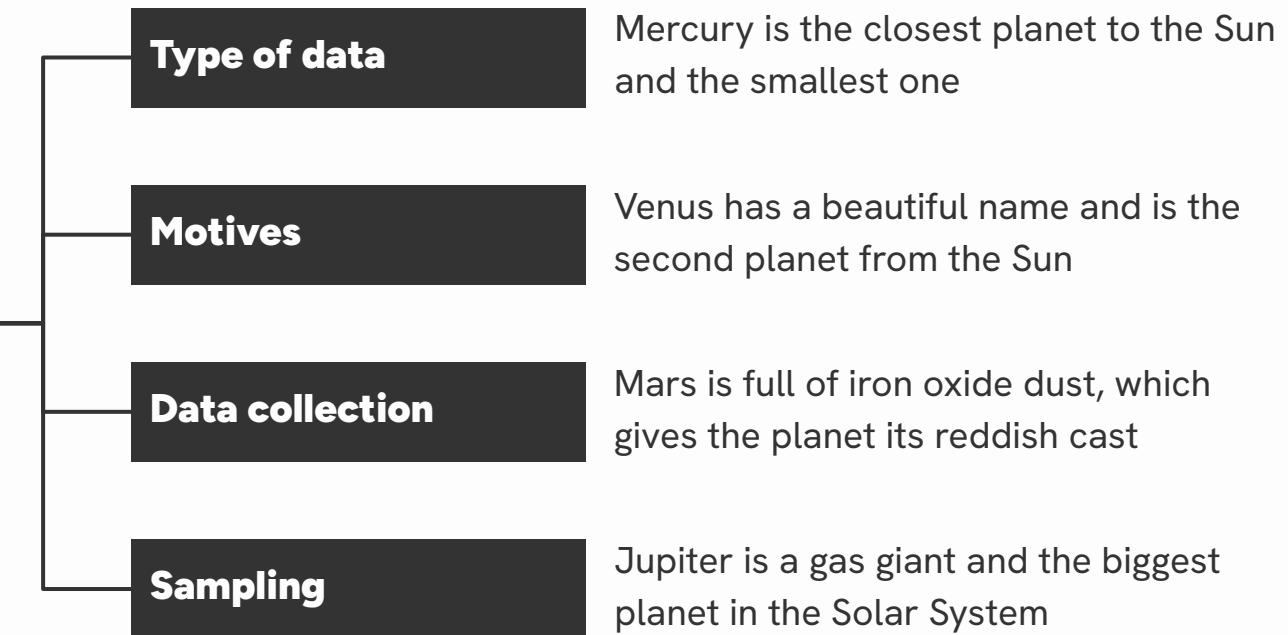
Theoretical framework		
Key terms	Relevant theories	Our framework
<ul style="list-style-type: none">• Mercury is small• Earth harbors life• Jupiter is big	<p>Theory 1</p> <p>Saturn is a gas giant and has rings. It's composed mostly of hydrogen and helium</p> <p>Theory 2</p> <p>Neptune is the farthest planet from the Sun in Solar System and also an ice giant</p>	 <p>Venus has a beautiful name and is the second planet from the Sun. It's very hot</p>

Schedule

Methodology



Mercury



Analysis & development

Phase 01

- Mercury is the closest planet to the Sun and the smallest one in the Solar System—it's a bit larger than the Moon
- Jupiter is a gas giant, the biggest planet in the Solar System and the fourth-brightest object in the night sky
- Neptune is the farthest planet from the Sun. It's also the fourth-largest planet by diameter in the Solar System

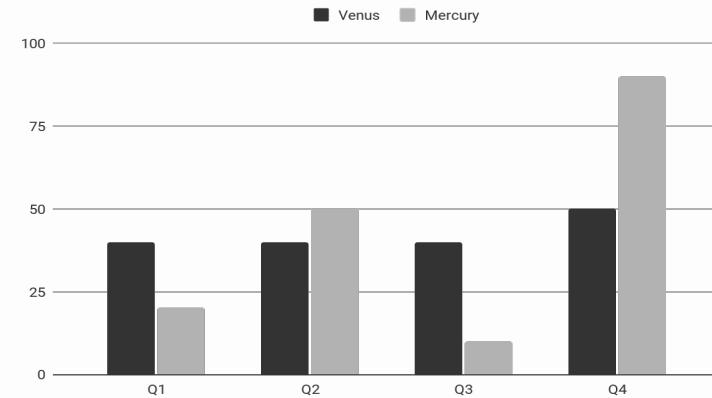
Phase 02

- Venus has a beautiful name and is the second planet from the Sun. It's terribly hot—even hotter than Mercury
- Saturn is a gas giant and has several rings. This planet is composed mostly of hydrogen and helium
- Earth is the third planet from the Sun and the only one that harbors life in the Solar System

Analysis & development

Mercury is the closest planet to the Sun and the smallest one in the Solar System. The planet's name has nothing to do with the liquid metal.

- The Sun is the star at the center of the Solar System
- Jupiter is the biggest planet in the entire Solar System
- Saturn is composed mostly of hydrogen and helium



Venus

Venus has a beautiful name

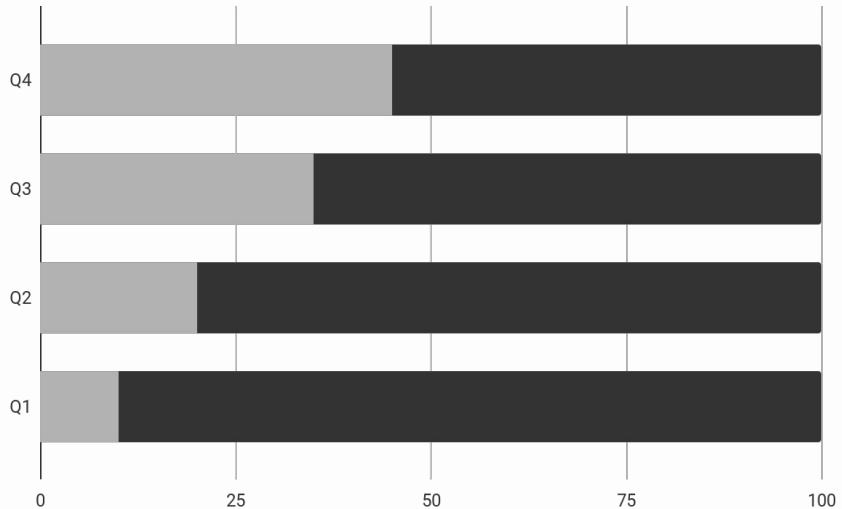


Mercury

Mercury is quite a small planet

Follow the link in the graph to modify its data and then paste the new one here. [For more info, click here](#)

Analysis of the results



Mercury

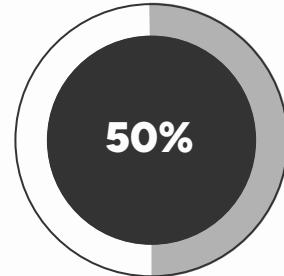
Mercury is quite a small planet

Venus

Venus has a beautiful name

Mars

Despite being red, Mars is a planet very cold



Follow the link in the graph to modify its data and then paste the new one here. [For more info, click here](#)

This is a map



Venus

Venus is the second planet from the Sun



Mercury

Mercury is the closest planet to the Sun



Mars

Despite being red, Mars is a cold place

Discussion

Mars & Earth

Despite being red, Mars is actually a cold place. It's full of iron oxide dust, which gives the planet its reddish cast. Earth is the third planet from the Sun and the only one that harbors life in the Solar System. This is where we all live:

- Ceres is located in the main asteroid belt
- The Moon is Earth's natural satellite
- Neptune is very far away from us
- Pluto is now considered a dwarf planet



Discussion 1

Mercury is the closest planet to the Sun and the smallest one in the Solar System. It's bit larger than the Moon



Discussion 2

Venus has a beautiful name and is the second planet from the Sun. Venus is a lot hotter than Mercury

Conclusions



Mars

Despite being red, Mars is actually a cold place. It's full of iron oxide dust



Mercury

Mercury is the closest planet to the Sun and the smallest one in the Solar System



Venus

Venus has a very beautiful name and is the second planet from the Sun



Neptune

Neptune is a big planet. It is the fourth-largest planet by diameter in the Solar System

Bibliographical references

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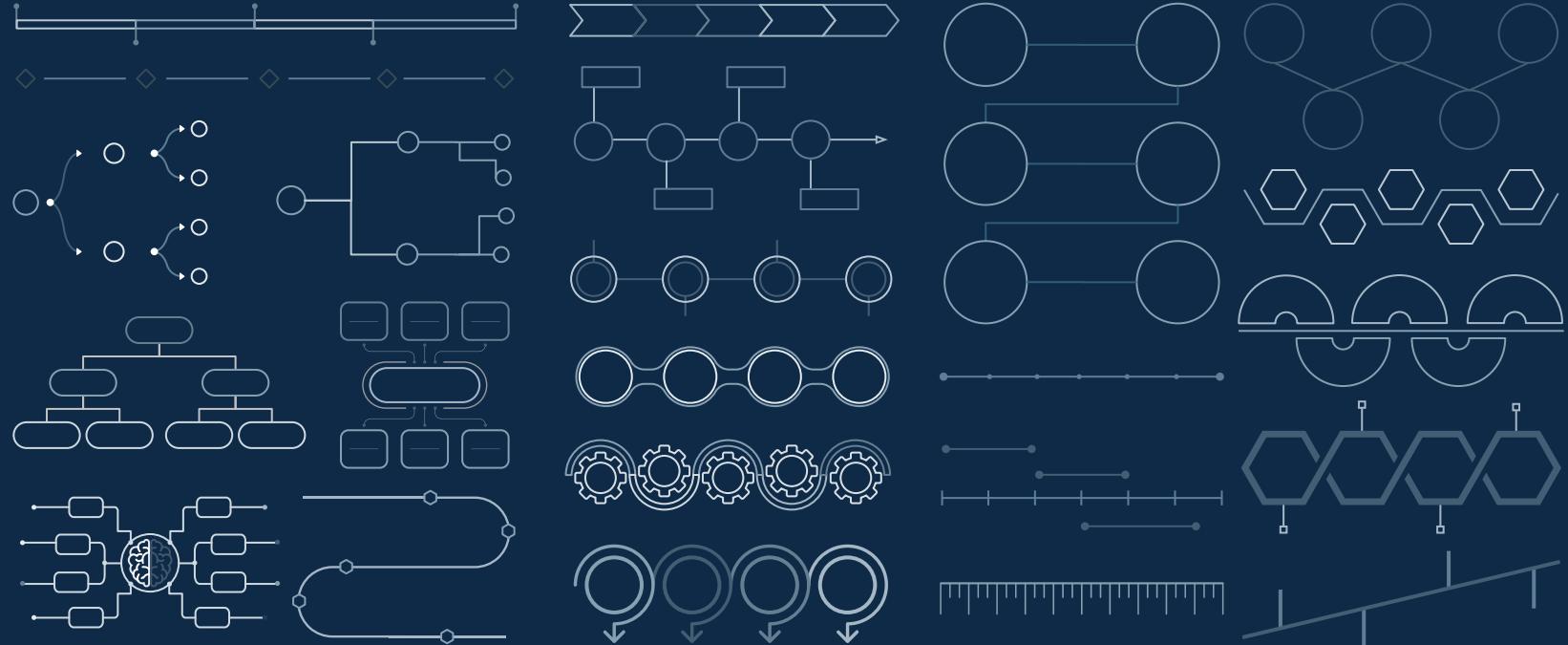
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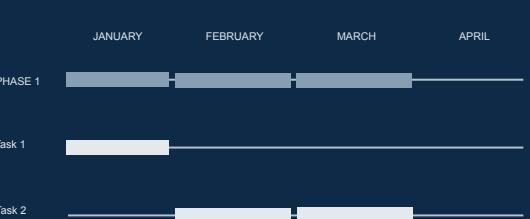
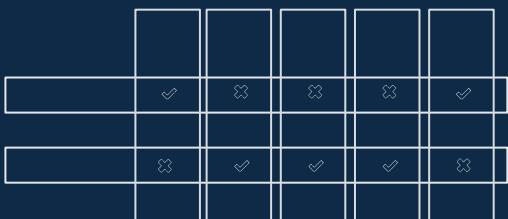
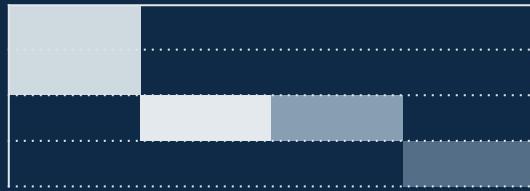
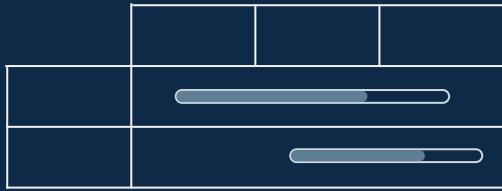
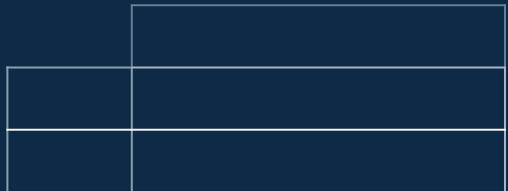
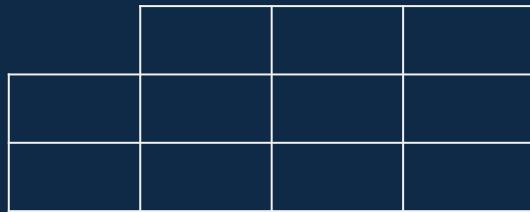
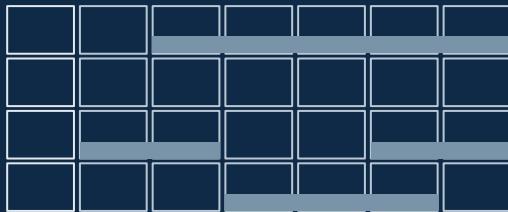
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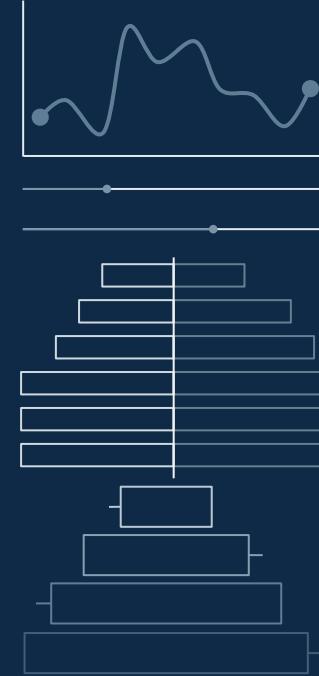
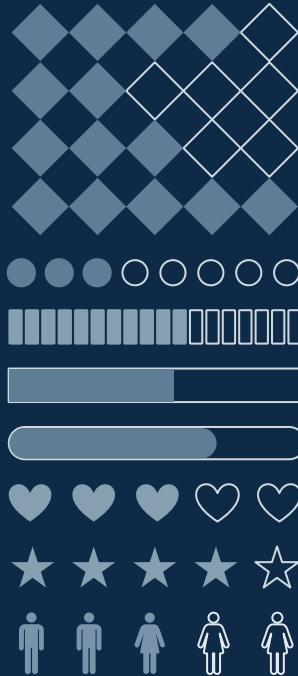
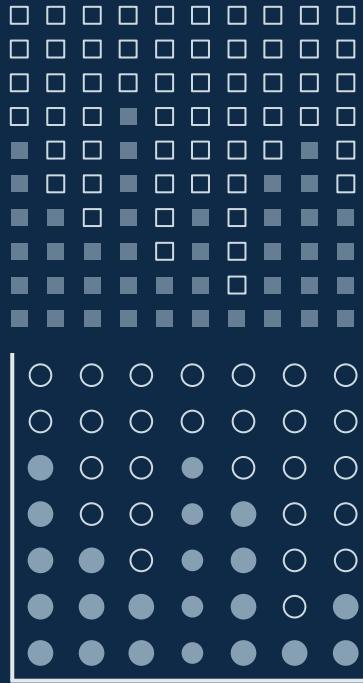












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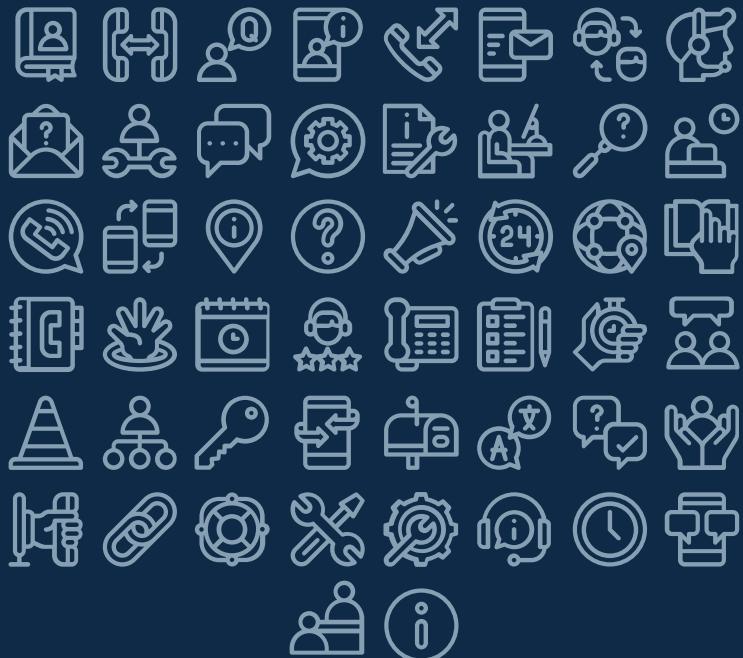
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