Classification of Systems from Component Characteristics

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Complex Systems Architecture

Motivation

- Seminal works in Sociology, Biology, Information networks - Nature, Science
- Generalization leading to Unifying Principles
- “Engineering should be at the centre of these developments, and contribute to the development of new theory and tools” (Ottino, Nature Jnl, 2004)
- “Engineers seem a little bit indifferent as if engineering is at the edge of the science of comlexity” (Zhi-Quang, AIChe Jnl, 2007)

“I think the next century will be the century of complexity”

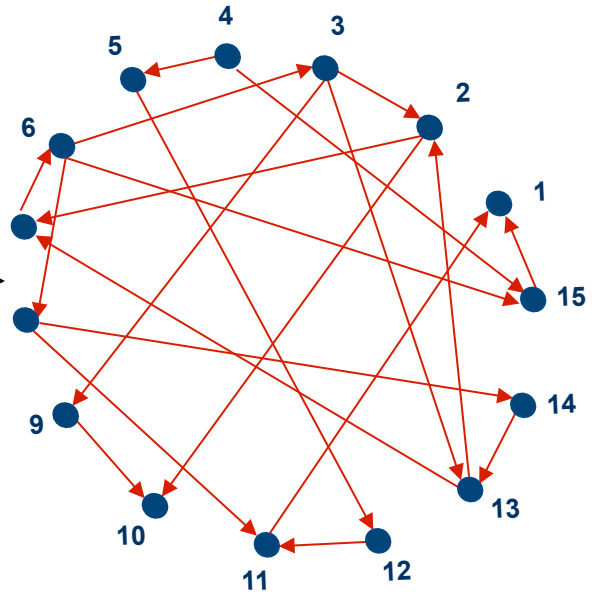
– Stephen Hawkins (2000)

Some systems considered in our research

- **Biology**
  - Ecoli
  - Yeast
- **Language**
  - English (language)
  - French (language)
  - Japanese (language)
- **Software**
  - Apword (word processor)
  - Linux (OS)
  - Mysql (Database)
- **Mechanical**
  - Aircraft Engine
  - Refrigerator
  - Robot
- **Electrical Systems**
  - Digital Fractional Multiplier (s208)
  - Digital Fractional Multiplier (s420)
  - Digital Fractional Multiplier (s838)
  - Traffic control system (s382)
  - Traffic control system (s400)
  - ALU (74181)
  - ALU (c880)
  - ALU (c2670)
  - Forward logic chips (s9234)
  - Forward logic chips (s13207)
  - ECAT (c499)
  - ECAT (c1908)
  - PLD (s641)
  - PLD (s713)

Systems Architecture

Systems architecture → **Graph** →



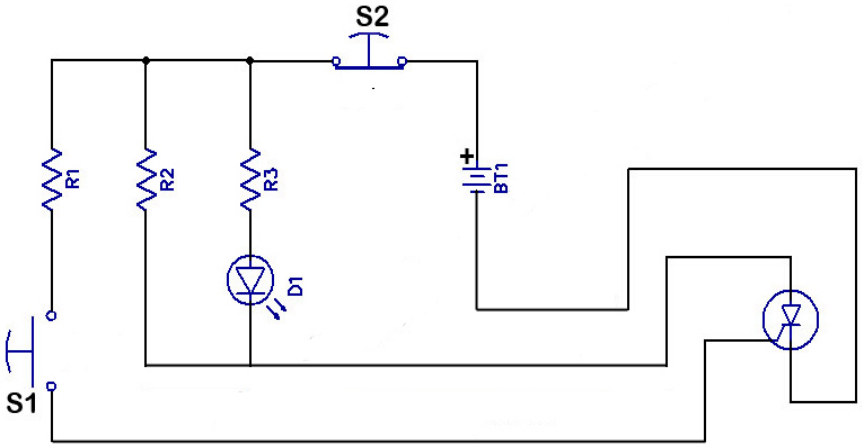
System	Node	Edge
Biological	Gene	Transcription reaction
Electrical	Gate	Current flow
Social	People	Interaction
Language	Words	Example follows

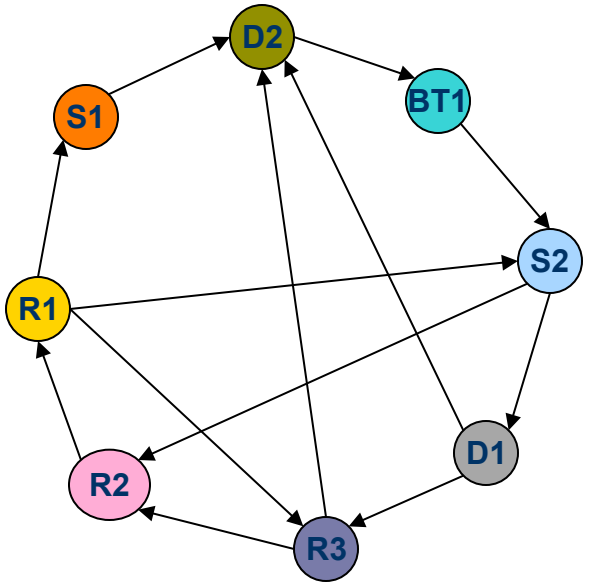
Electrical Systems Architecture → Graph

- **An example**

Nodes : 8

Edges : 13





Electrical Systems Architecture → Graph

- **An example**

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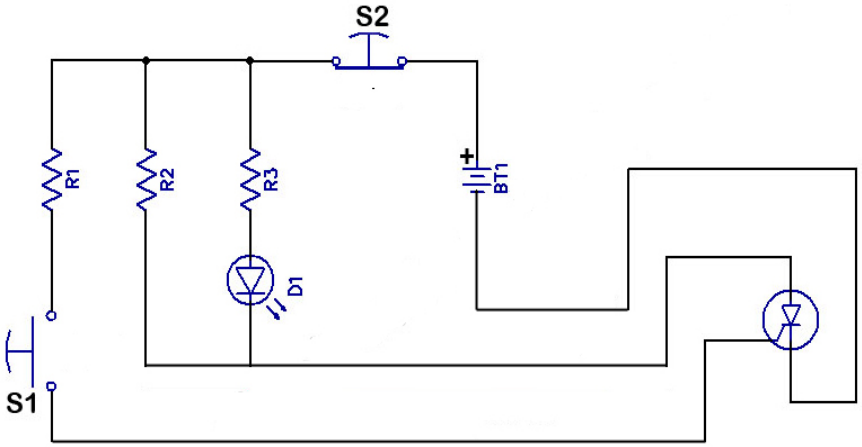
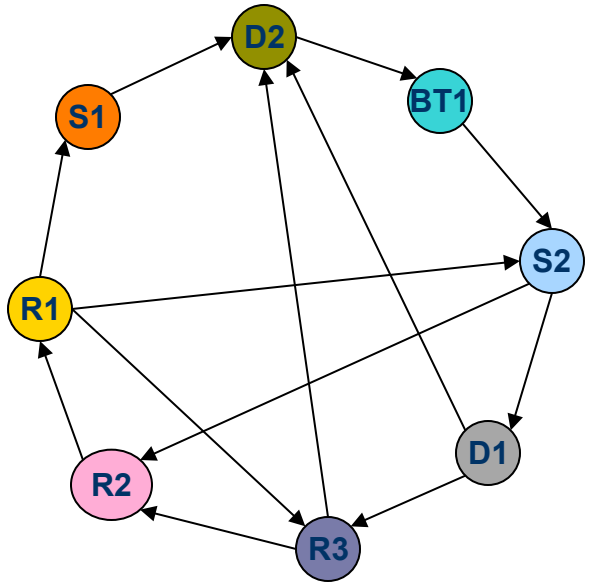




- **A more meaningful system studied**

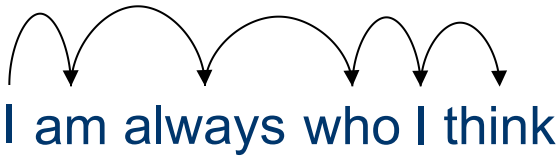
Forward Logic Circuit s38584

Nodes : 20717

Edges : 34182

Language Systems Architecture → Graph

- **An example**

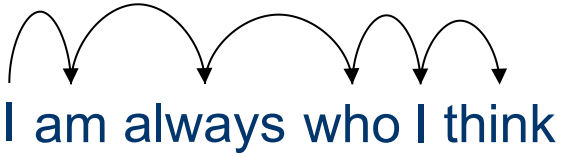


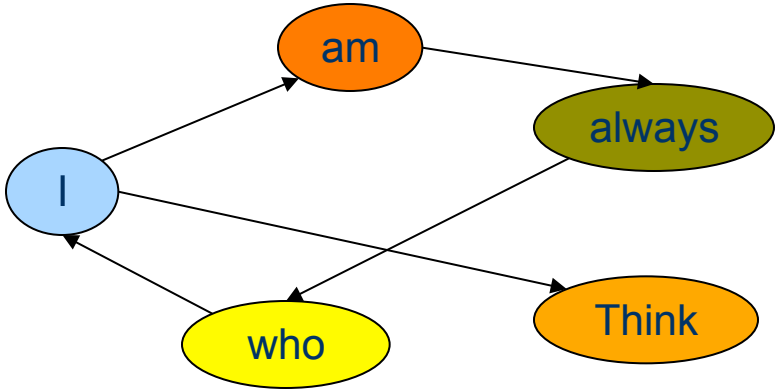
Language Systems Architecture → Graph

- **An example**

Nodes : 5

Edges : 5



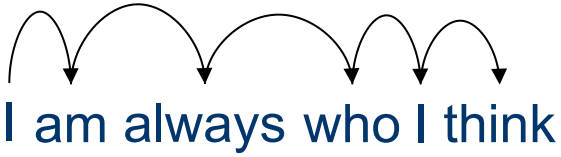


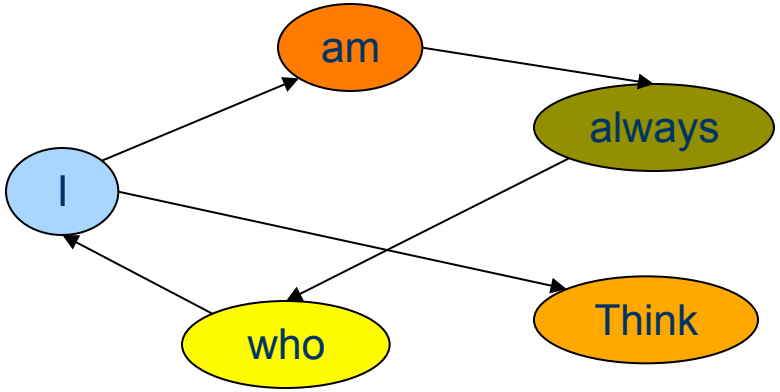
Language Systems Architecture → Graph

An example

Nodes : 5

Edges : 5





A more meaningful system studied

Network of text from Darwin

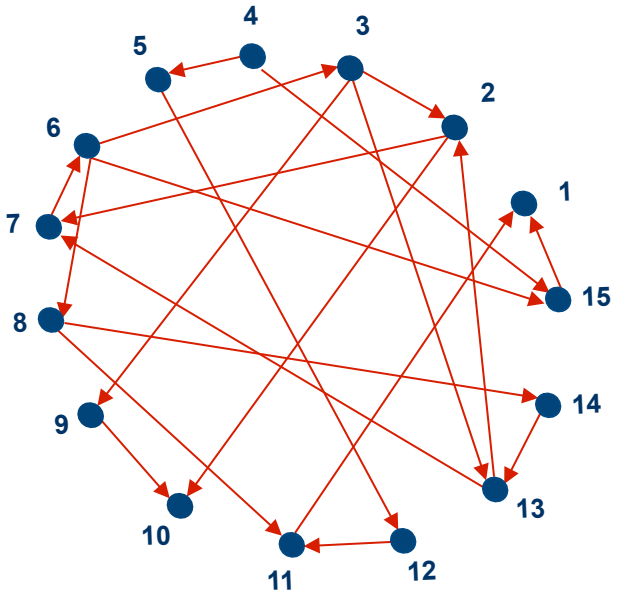
"The Origin of Species".

Nodes : 7724

Edges : 46281

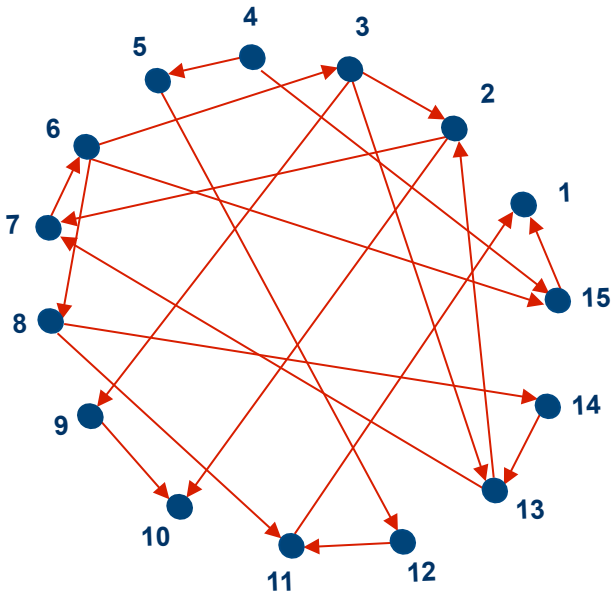
Introduction to Patterns

- Recurring sub graphs of interactions
- Simple building blocks of complex systems

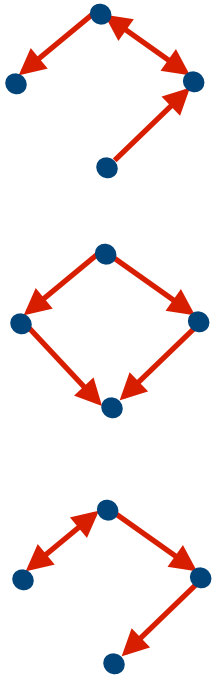


Introduction to Patterns

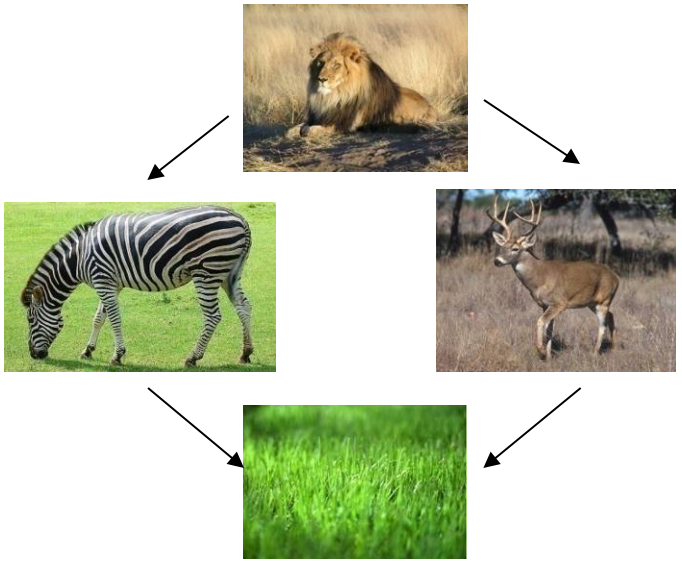
- Recurring sub graphs of interactions
- Simple building blocks of complex systems



4 Node Patterns



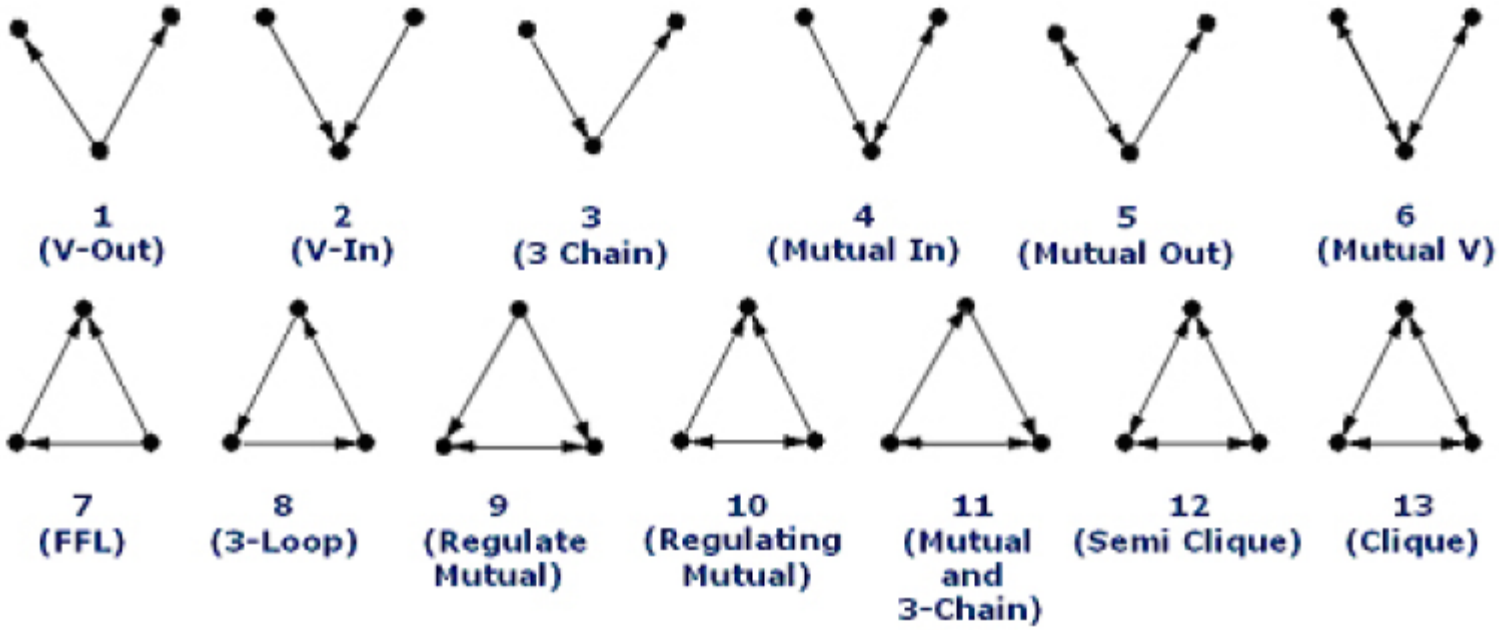
ecology - food webs



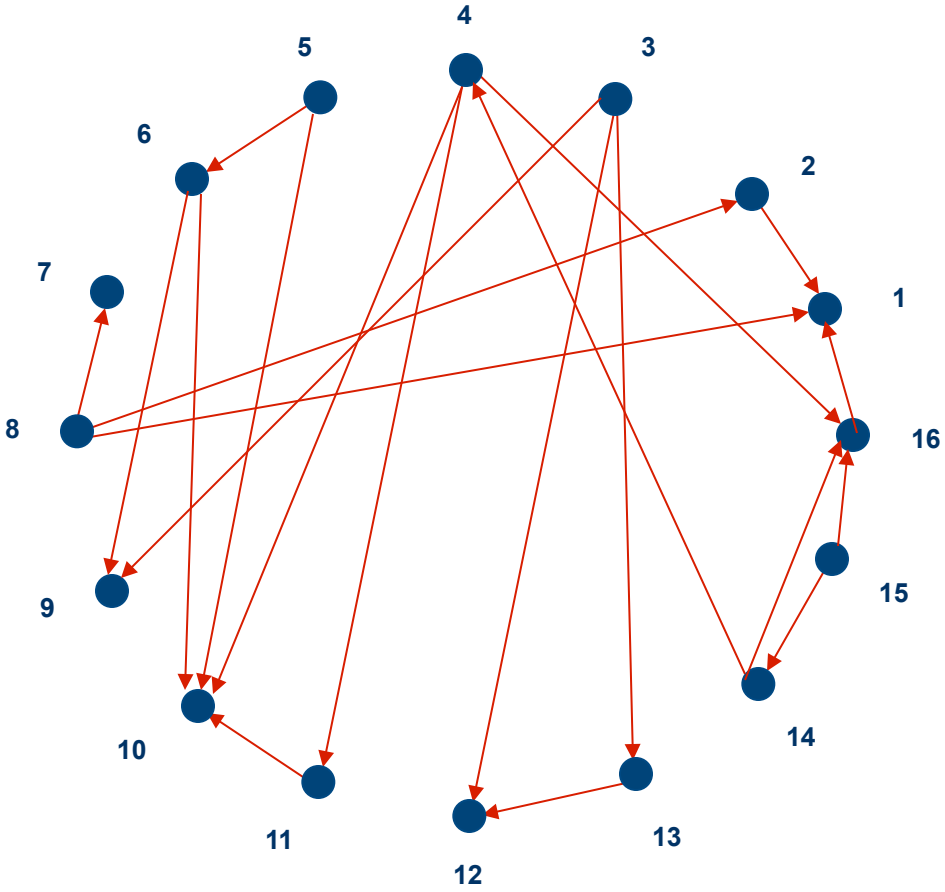
Pattern dominates

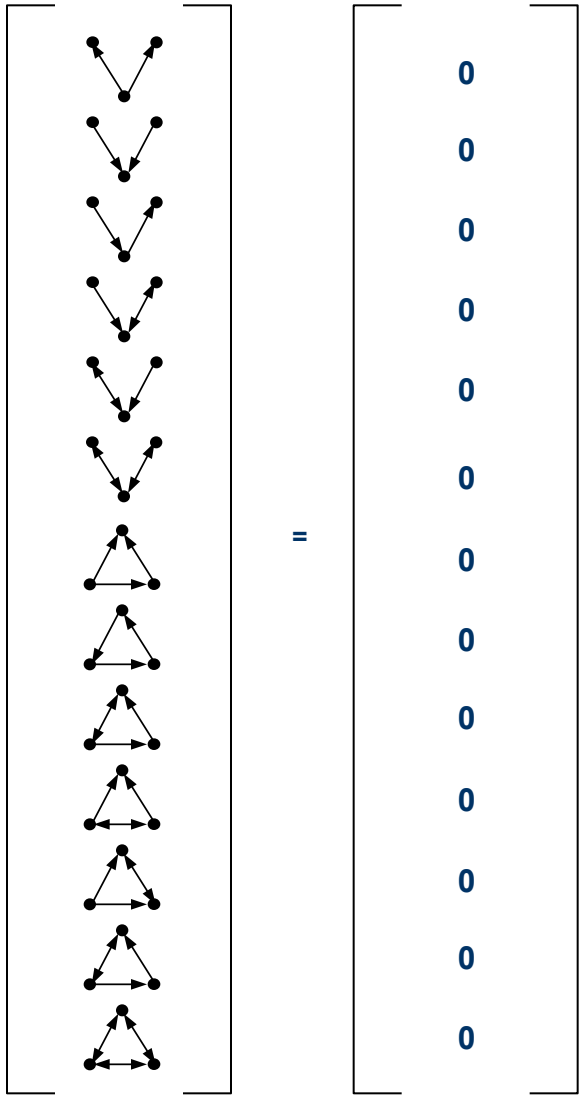
Patterns…

- 3 Components at a time

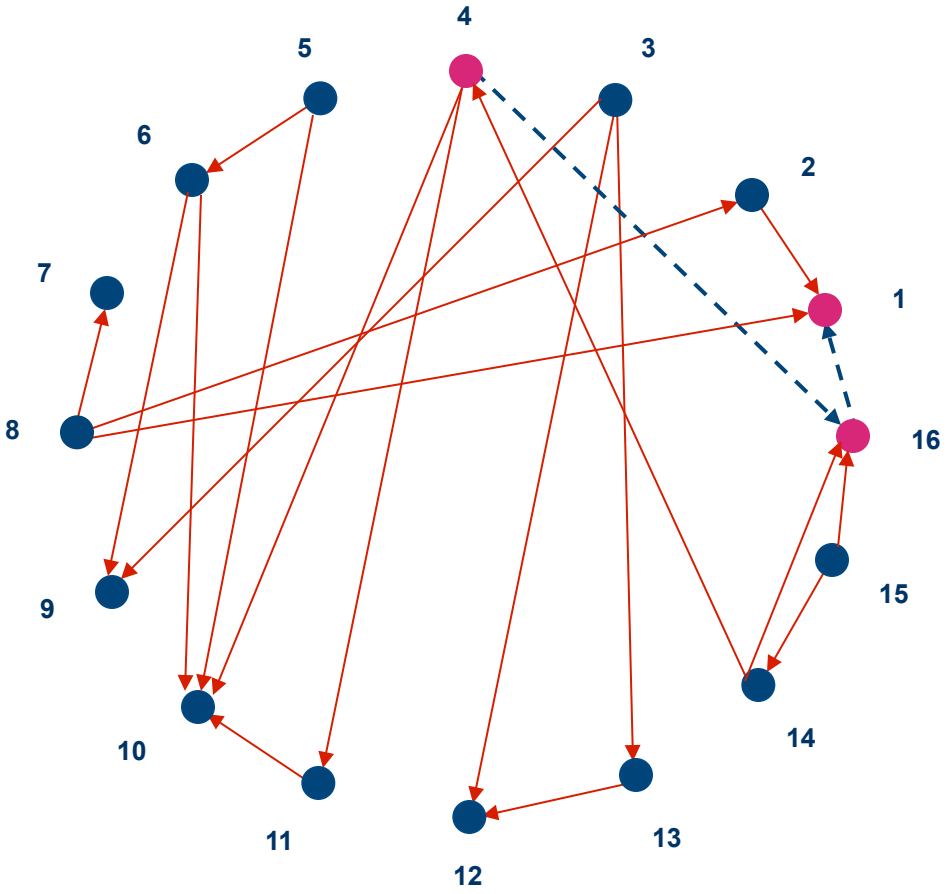


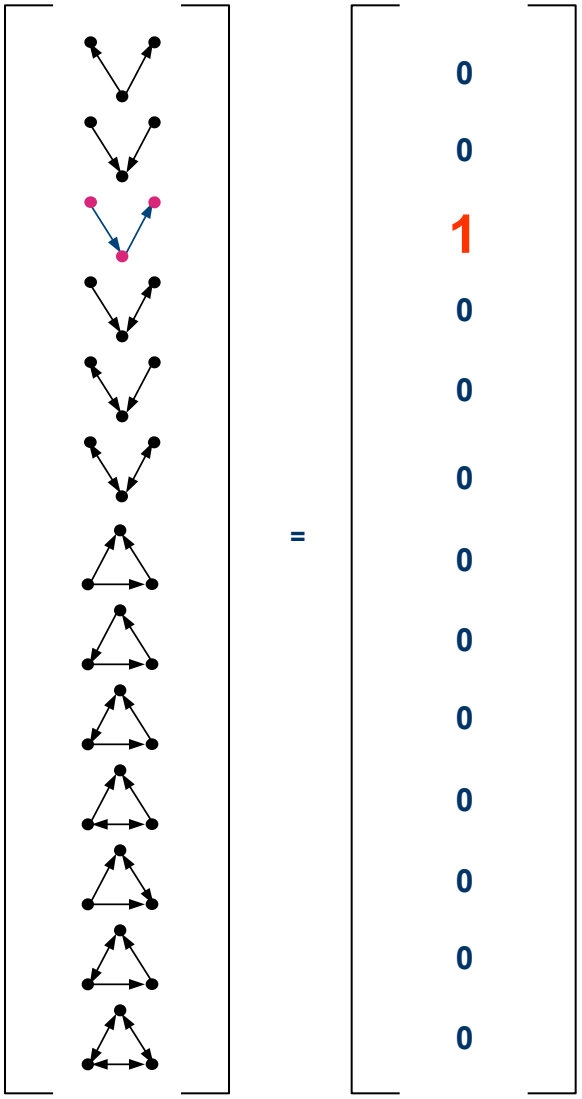
Pattern Counts



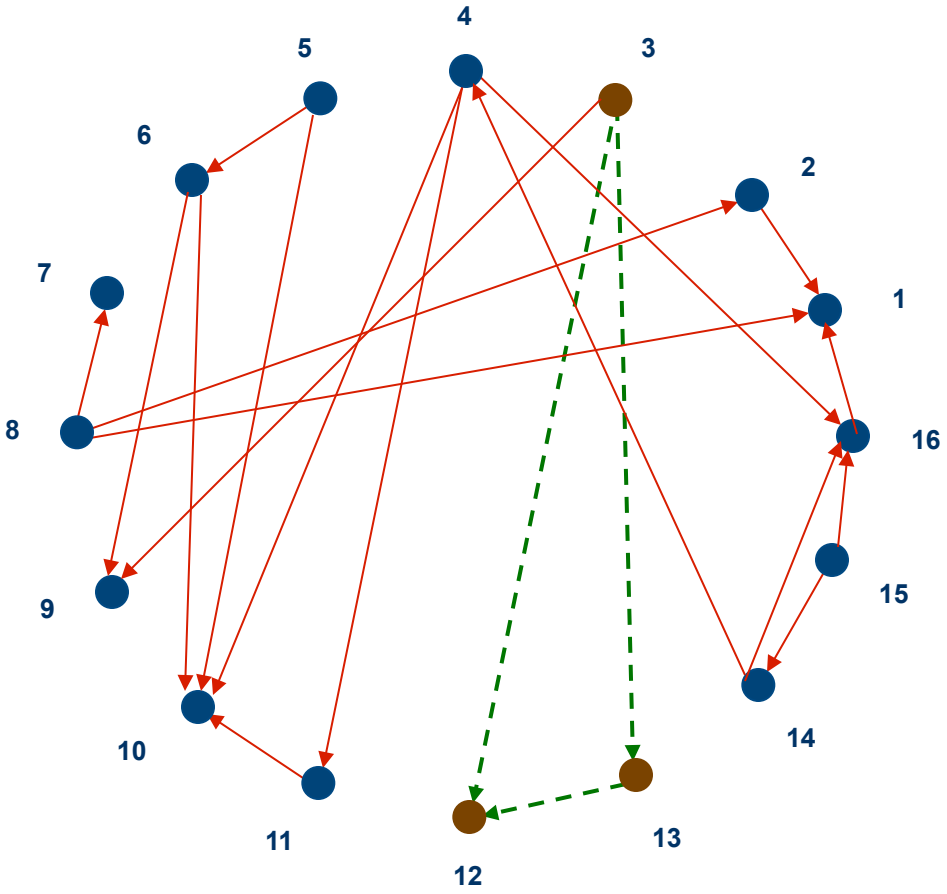


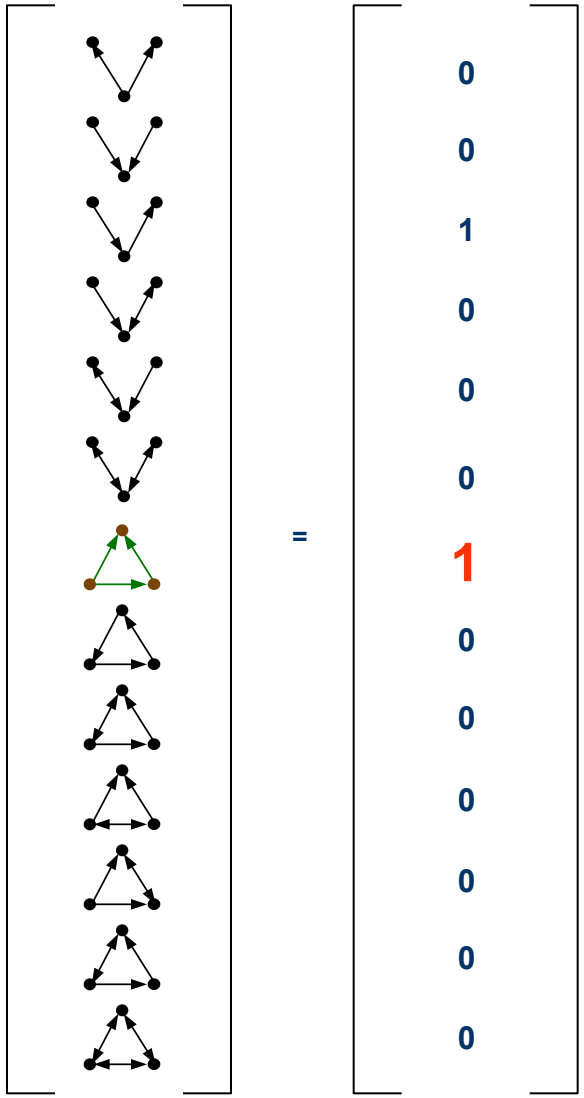
Pattern Counts



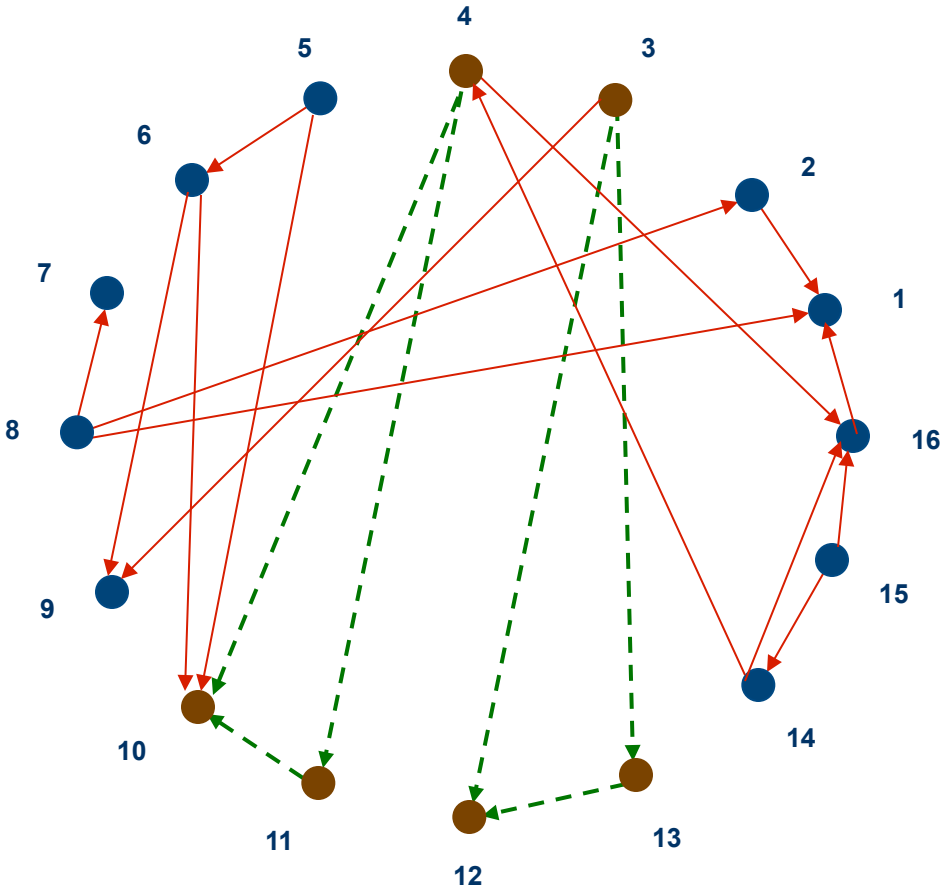


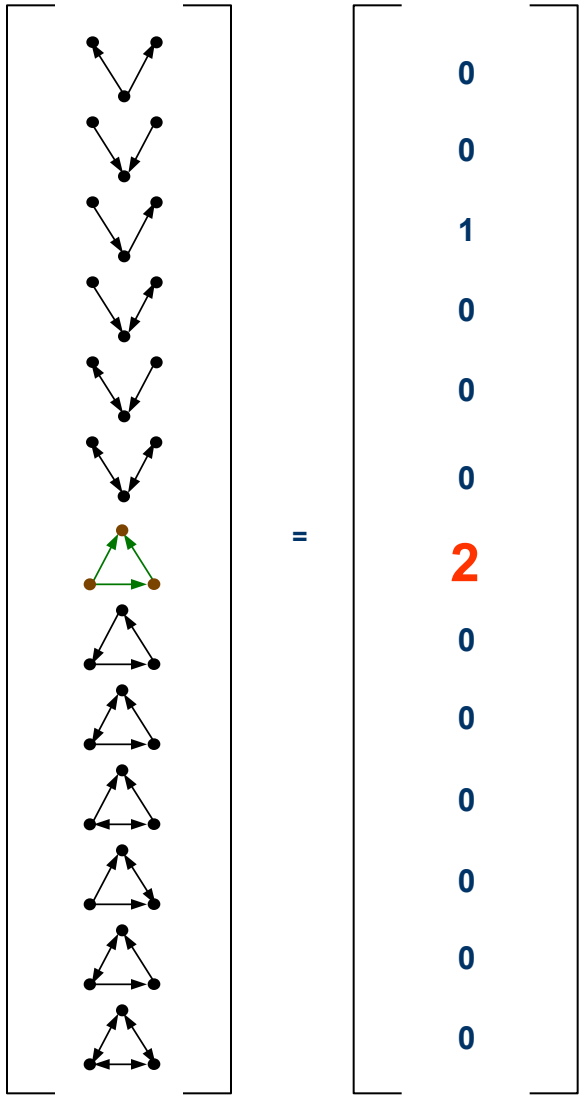
Pattern Counts





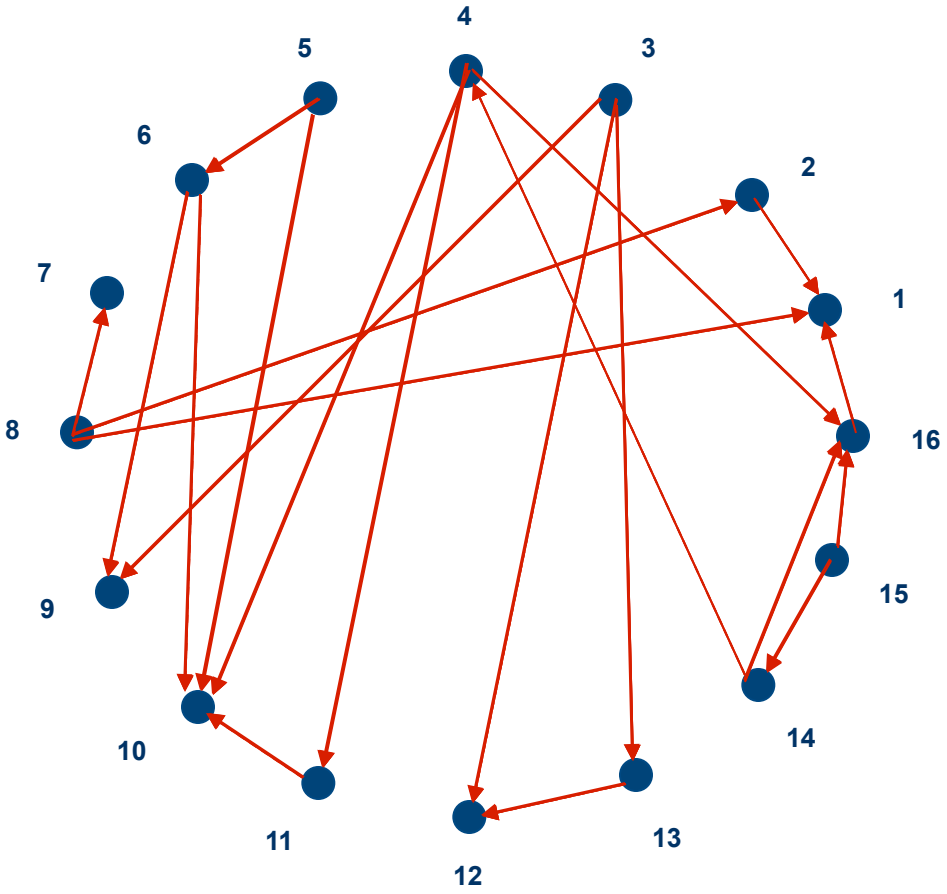
Pattern Counts

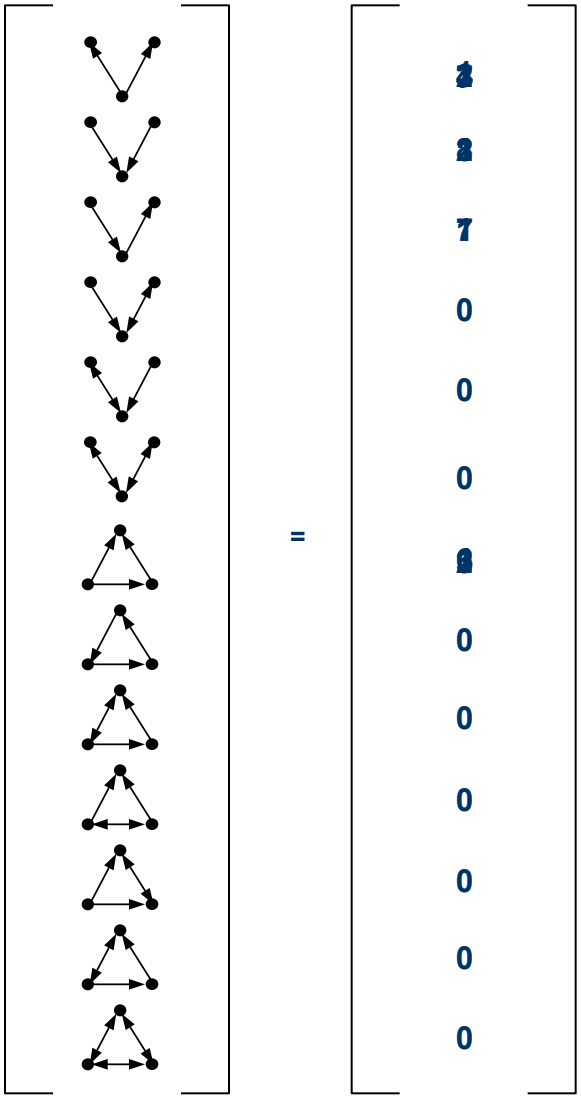




Pattern Counts

- Why are some patterns dominating?
- Why are some patterns missing?

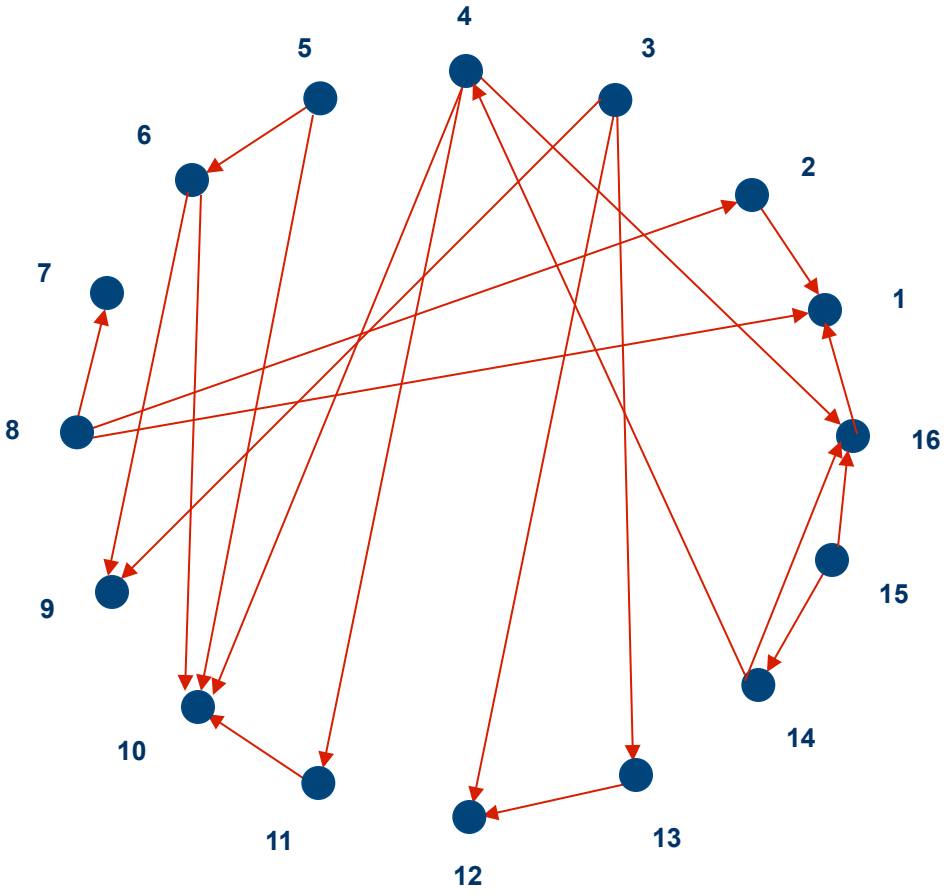


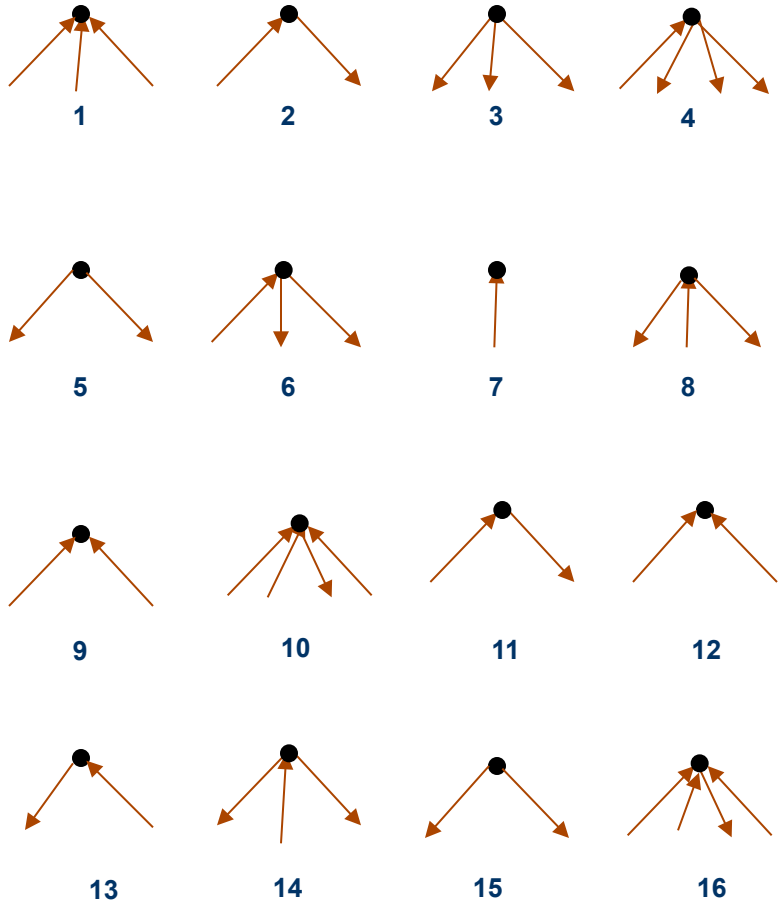


Key Chains

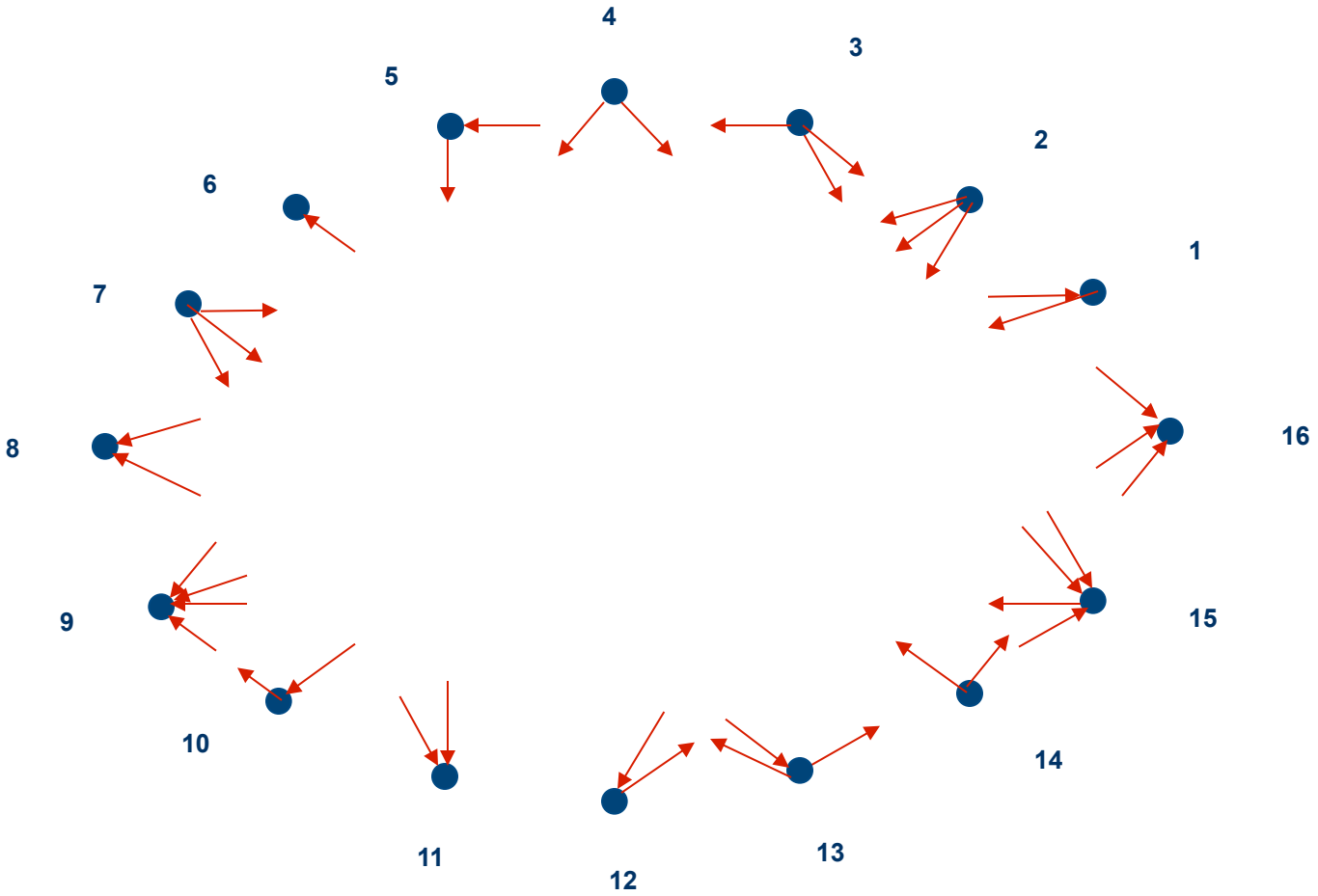
Designer builds System by interconnecting components.

Components with their in & out degrees are like key chains

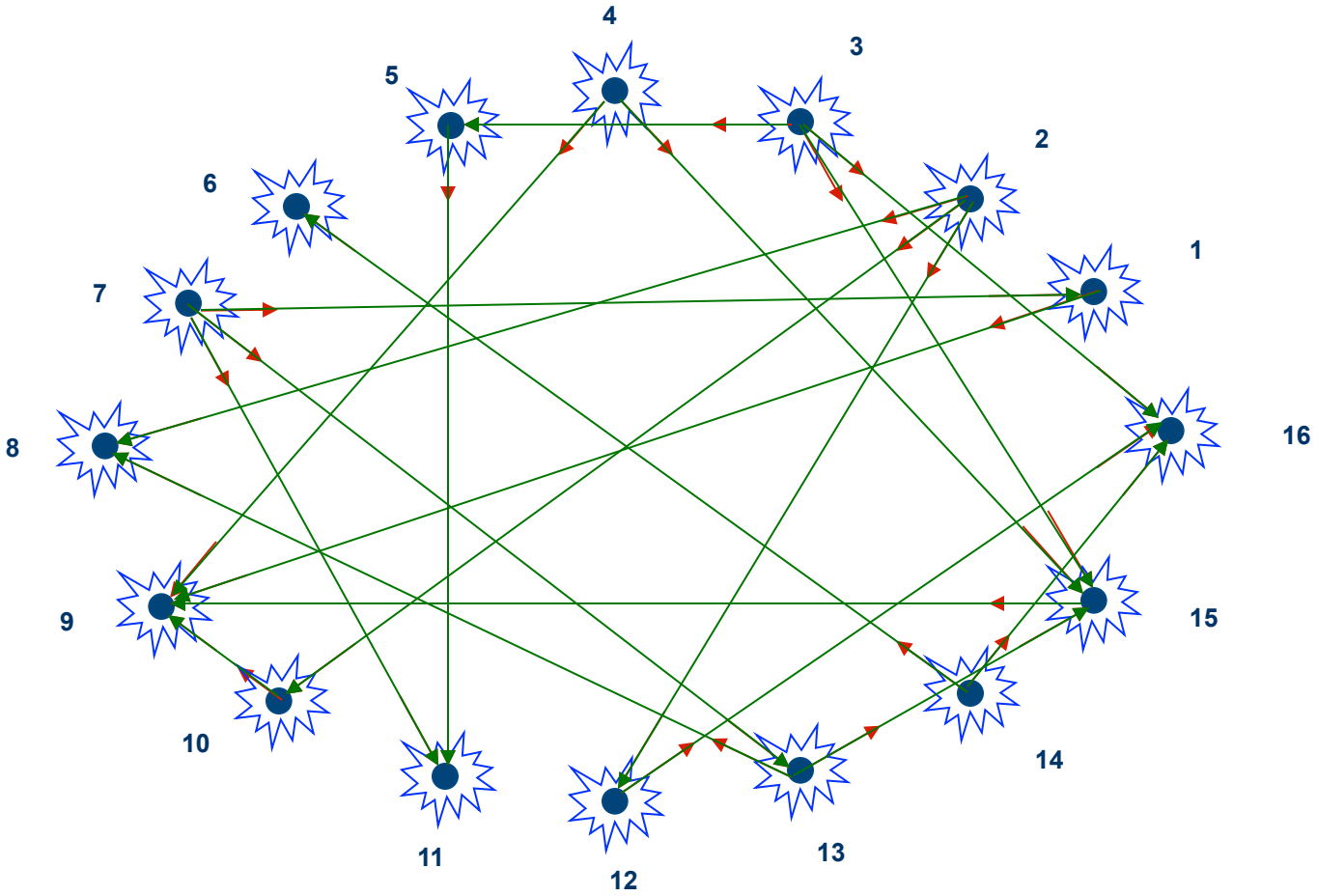




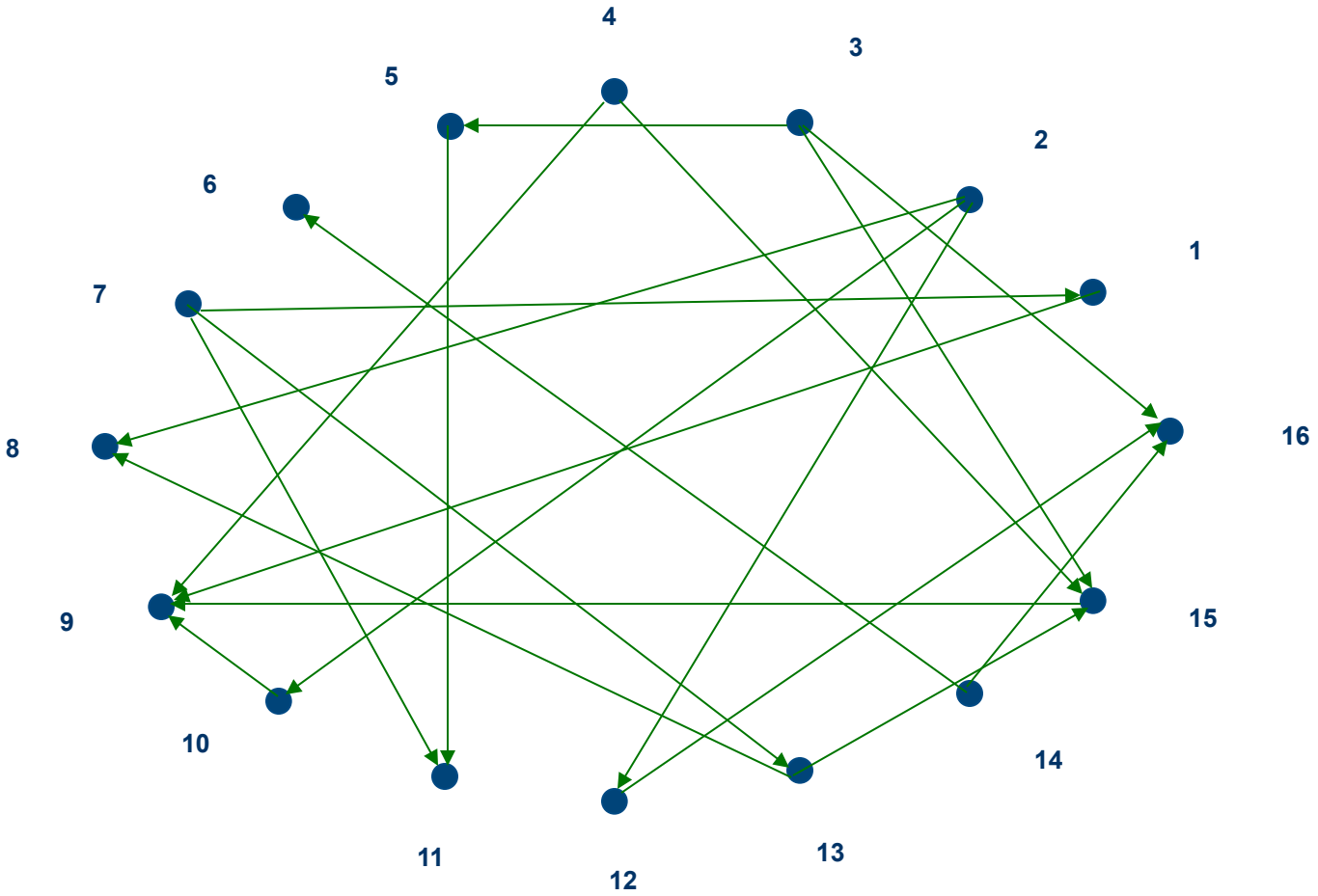
Key Chains



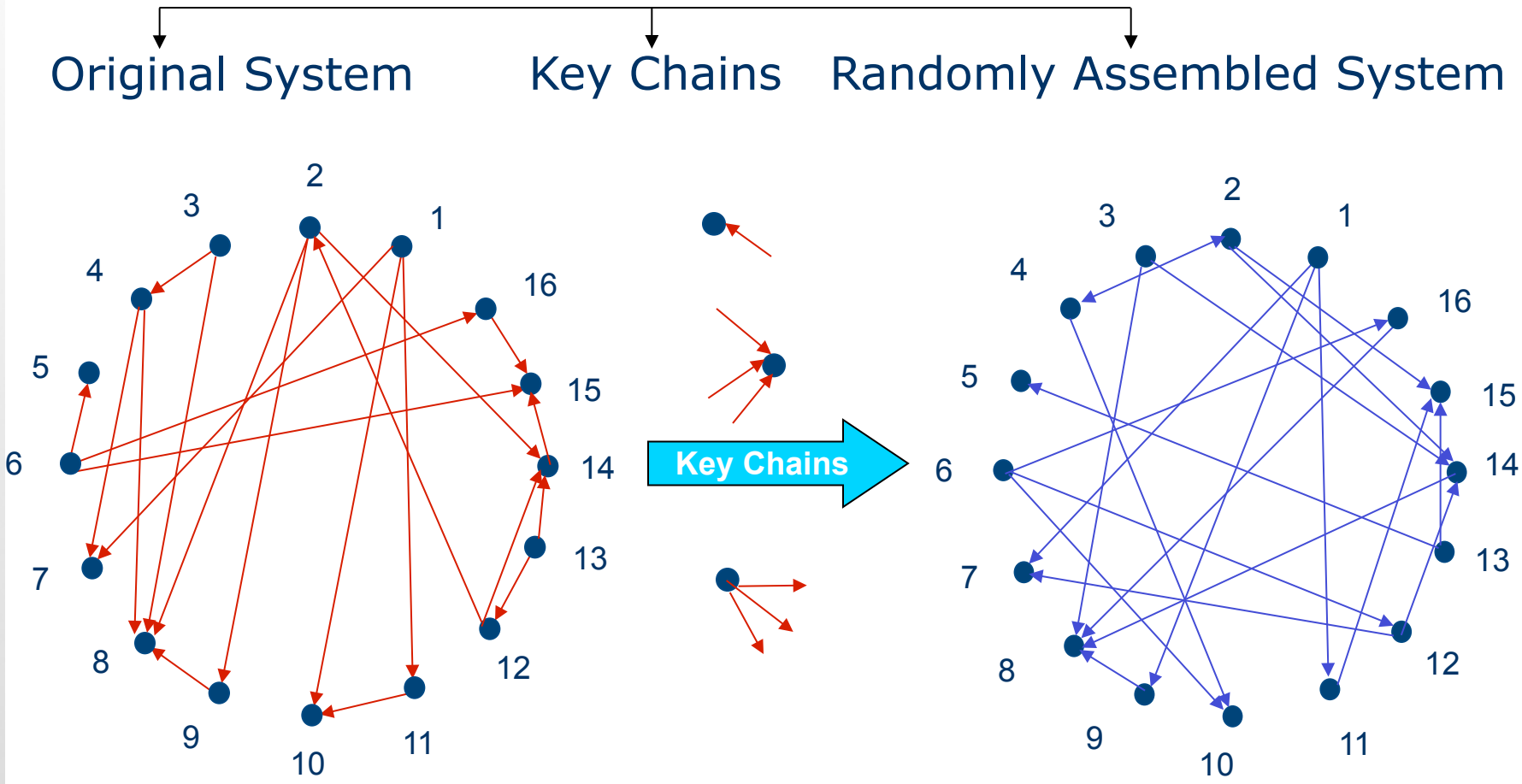
Key Chains



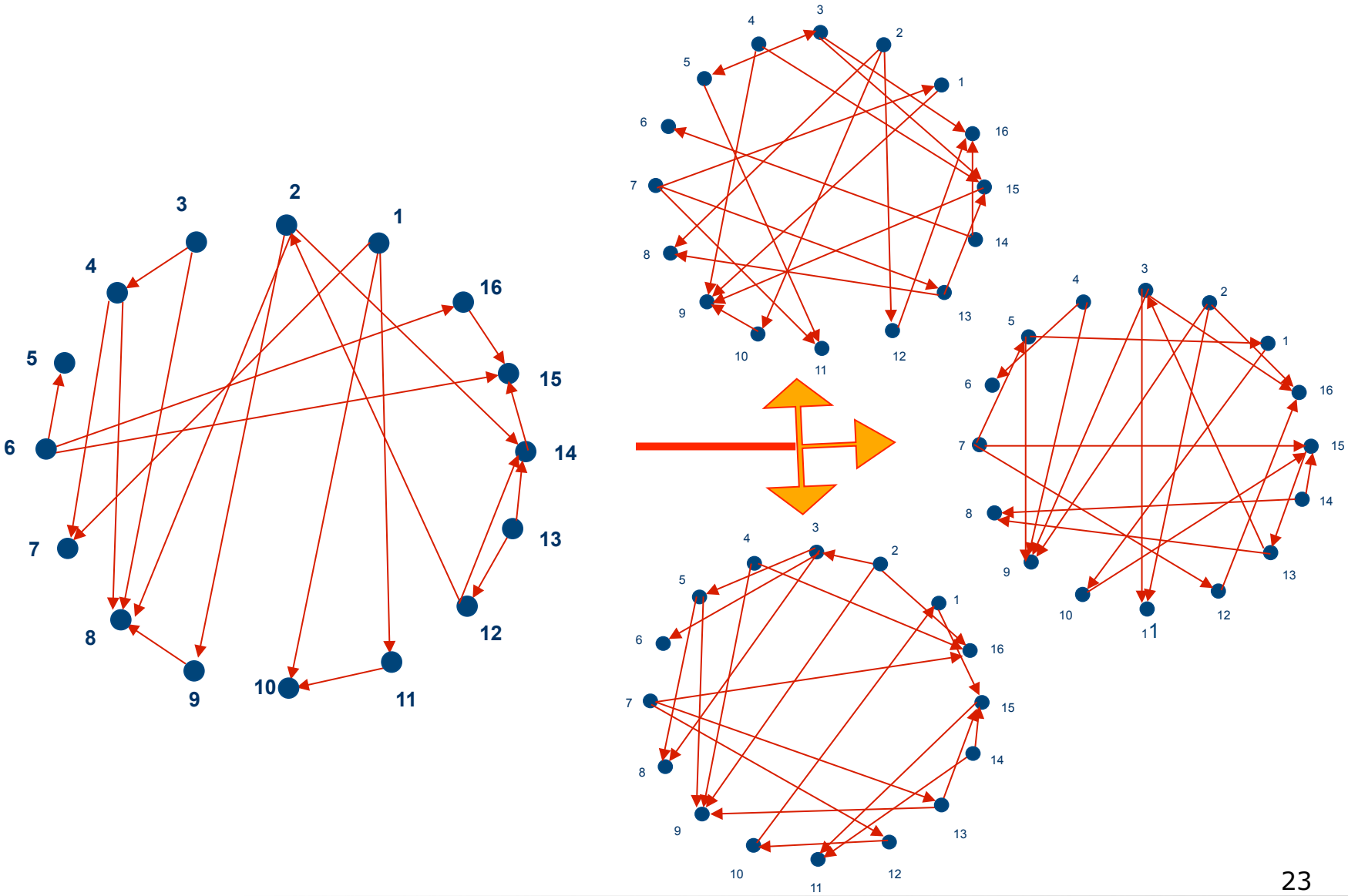
Key Chains



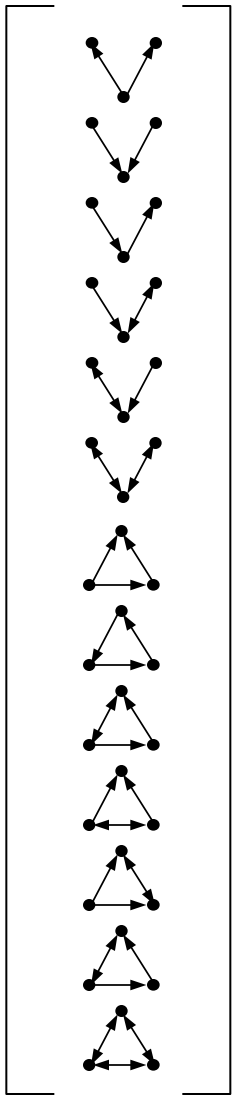
Random Assembly of Key Chains



Random Graphs



Pattern Counts in Random Graphs



=

$Rand_1$	$Rand_2$	...	$Rand_{1000}$
9	13		11
13	14		12
7	13		11
0	0		0
3	0		0
0	0		0
1	0		2
0	0		0
0	0		0
0	0		0
0	0		0
0	0		0
0	0		0

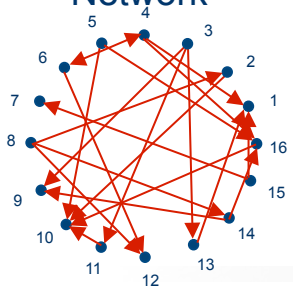
Pattern Counts in Random Graphs

		$Rand_1$	$Rand_2$		$Rand_{1000}$	μ_{rand}	σ_{SD}
	=	9	13	. . .	11	11.7	1.0
		13	14		12	12.7	1.0
		7	13		11	11.5	1.2
		0	0		0	0	0
		3	0		0	0	0
		0	0		0	0	0
		1	0		2	1.3	1.0
		0	0		0	0.1	0.3
		0	0		0	0	0
		0	0		0	0	0
		0	0		0	0	0
		0	0		0	0	0
		0	0		0	0	0

Motif Significance

Motif ID	Count
	860
	1100
	0
	401
	0
	0
	0
	0
	40
	0
	0
	0
	0

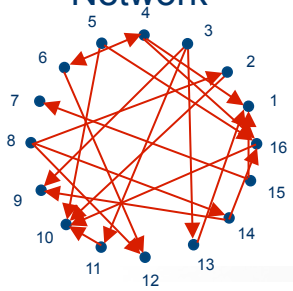
Network



Motif Significance

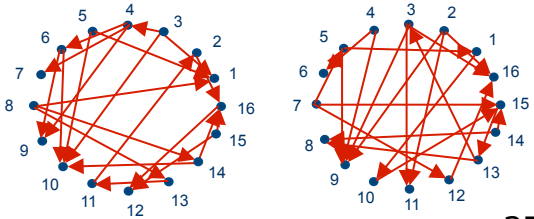
Motif ID	Count	Mean	SD
	860	856.9	1.8
	1100	1213.7	3.6
	0	0.0	0.0
	401	397.9	1.8
	0	3.1	1.8
	0	0.0	0.0
	0	0.0	0.0
	0	0.0	0.0
	40	1.1	1.0
	0	0.0	0.0
	0	0.0	0.0
	0	0.0	0.0
	0	0.0	0.0

Network



Key Chains

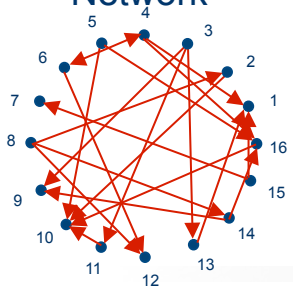
Random Graphs



Motif Significance

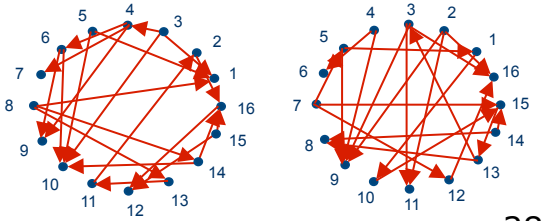
Motif ID	Count	Mean	SD	(Count-Mean)/SD
	860	856.9	1.8	1.7
	1100	1213.7	3.6	-31.6
	0	0.0	0.0	0.0
	401	397.9	1.8	1.7
	0	3.1	1.8	-1.7
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	40	1.1	1.0	38.9
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0

Network



Key Chains

Random Graphs



Motif Significance

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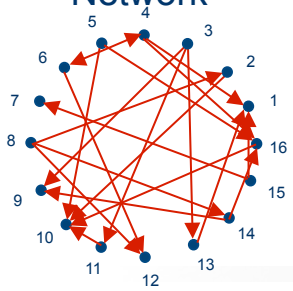
	0	0.0	0.0	0.0
	401	397.9	1.8	1.7
	0	3.1	1.8	-1.7
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	40	1.1	1.0	38.9
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0
	0	0.0	0.0	0.0

Why are some motifs under-represented?

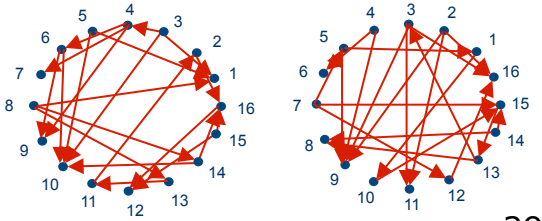
Why are some motifs over-represented?

Network



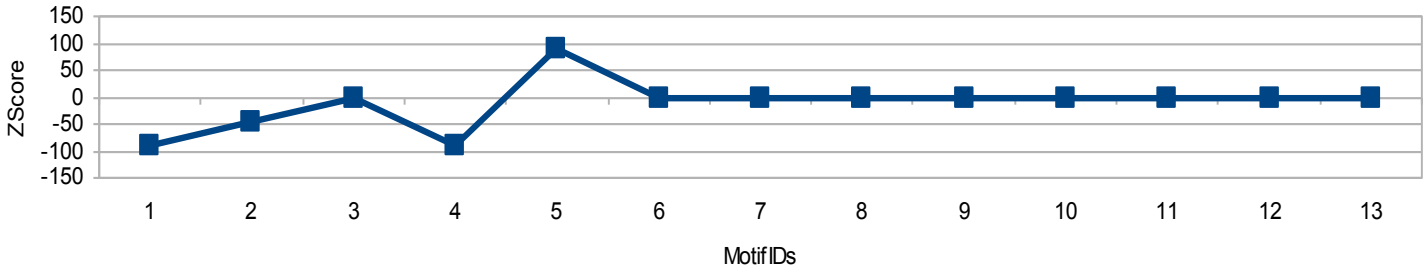
Key Chains

Random Graphs

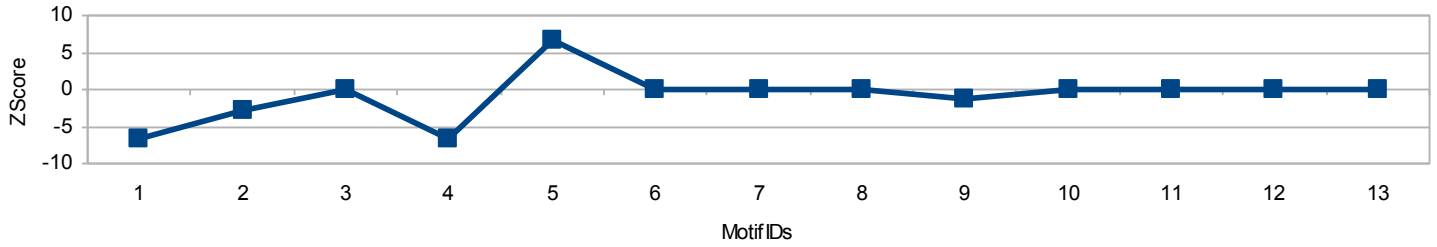


Motif Significance

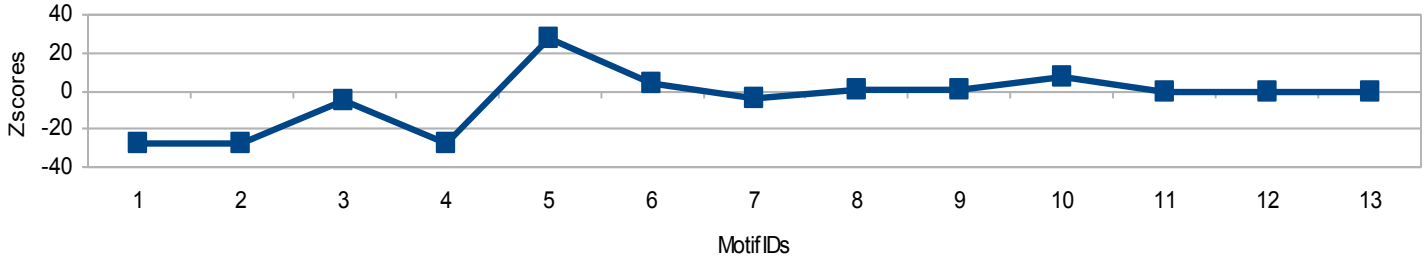
- Curiosity 1. (All systems show over/under represented motifs)



ECAT c1355

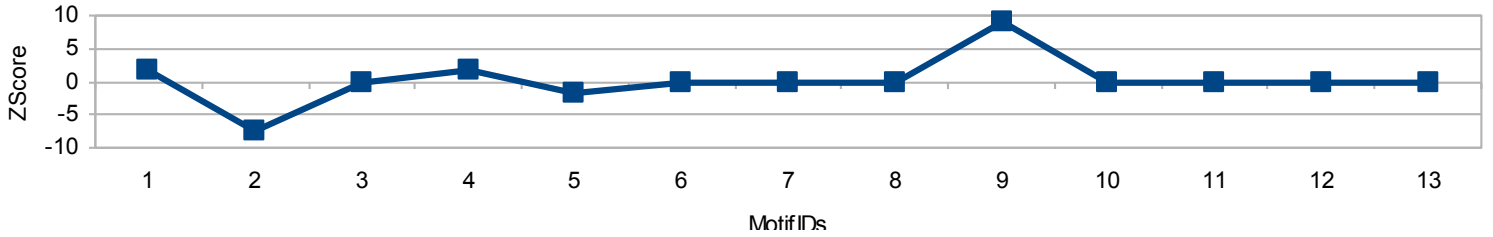


Traffic S444

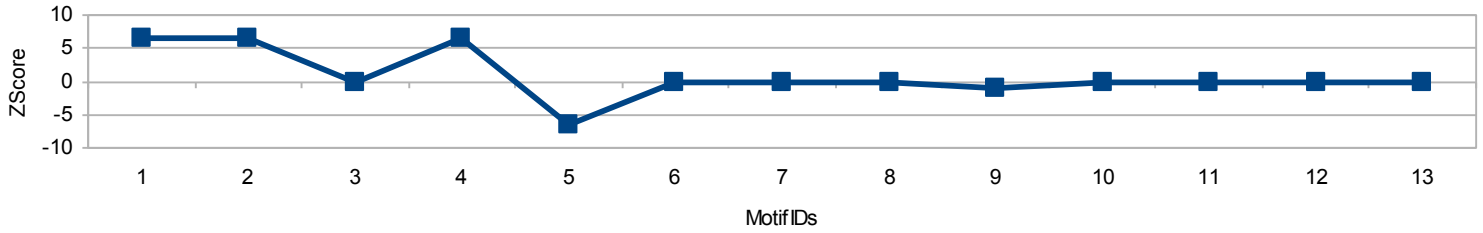


Software (Xmms)

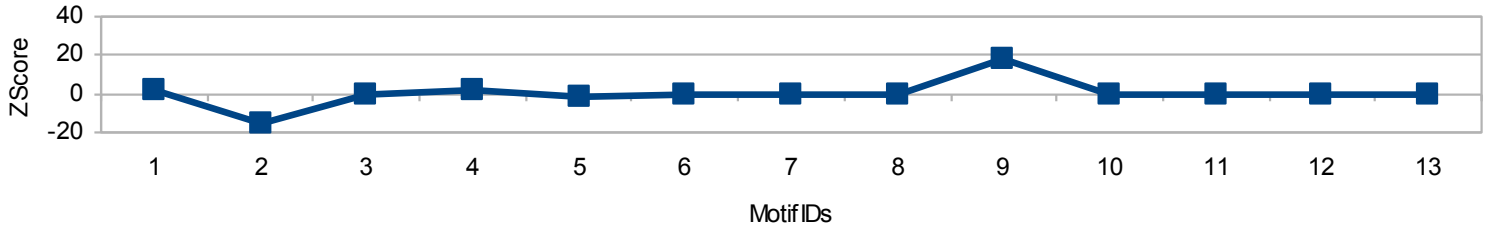
Motif Significance



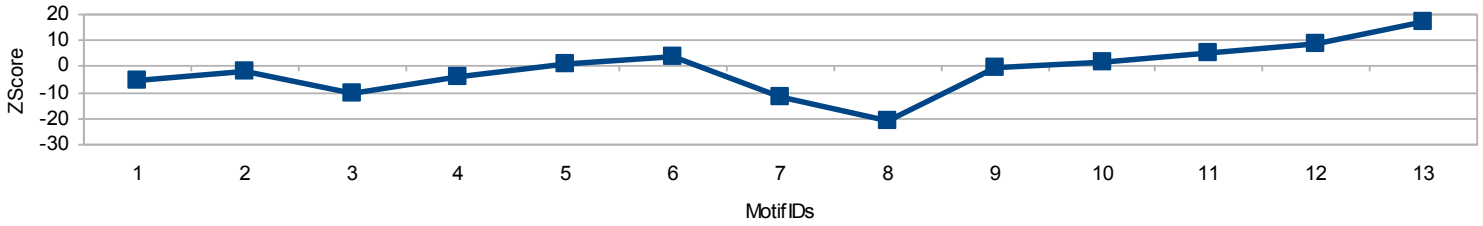
Digital s208



PLD s820

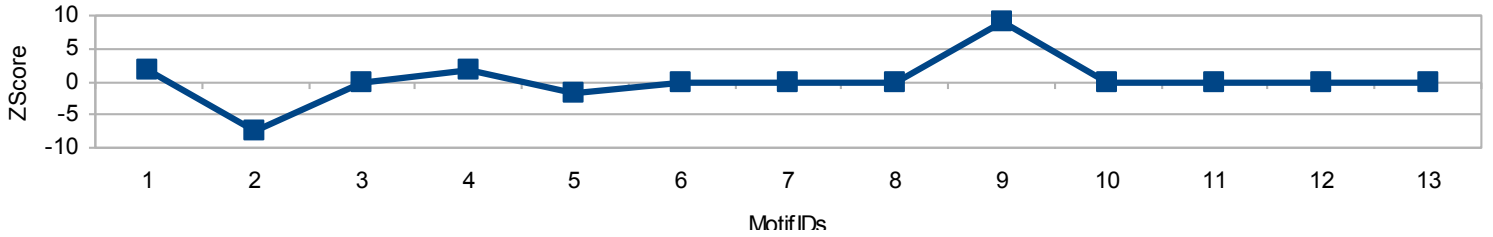


Digital s420

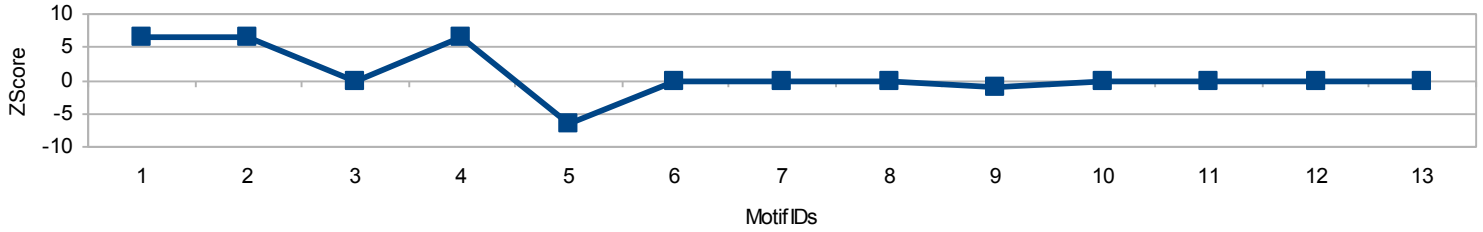


Aircraft

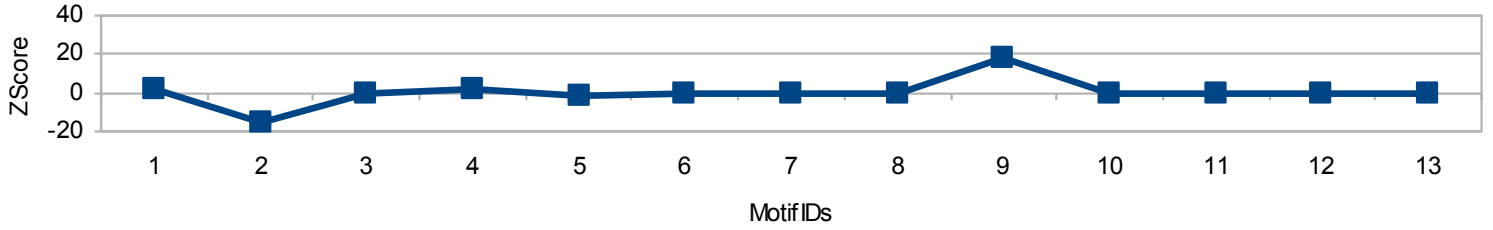
Motif Significance



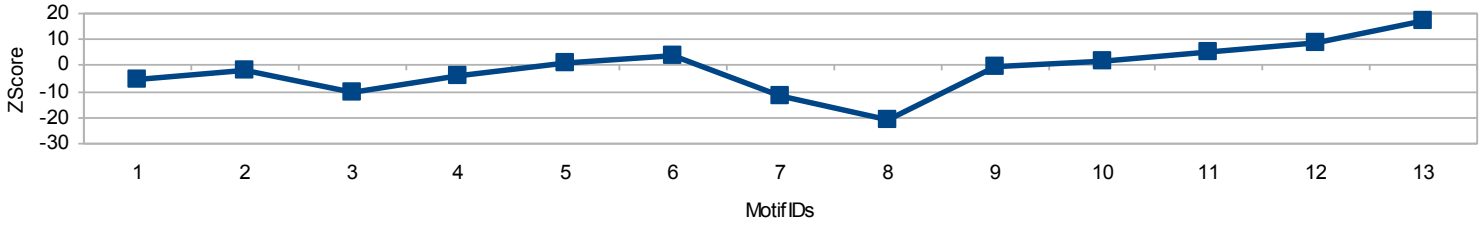
Digital s208



PLD s820

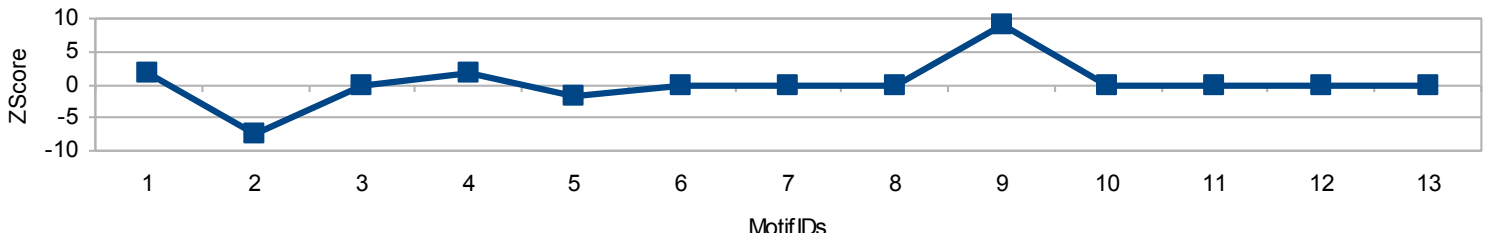


Digital s420

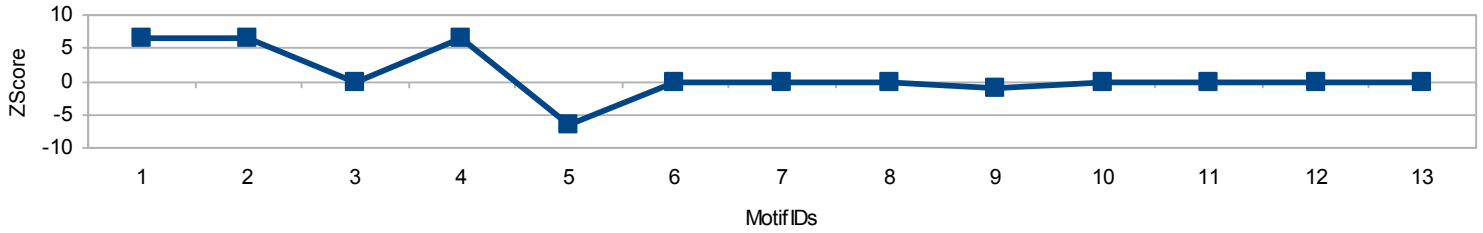


Aircraft

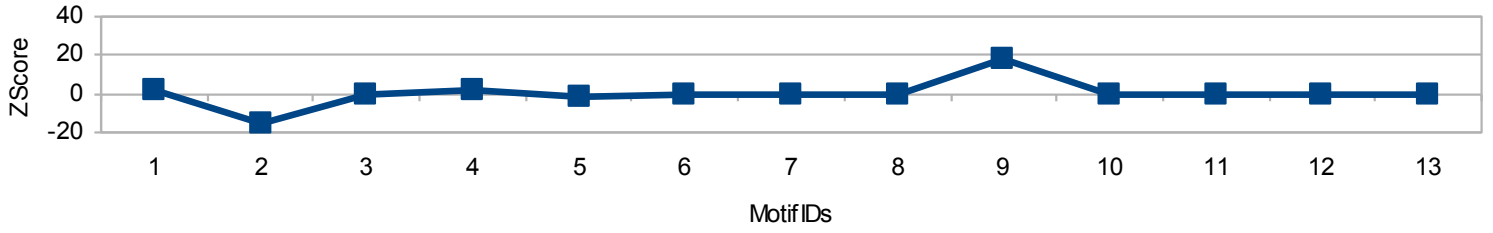
Motif Significance



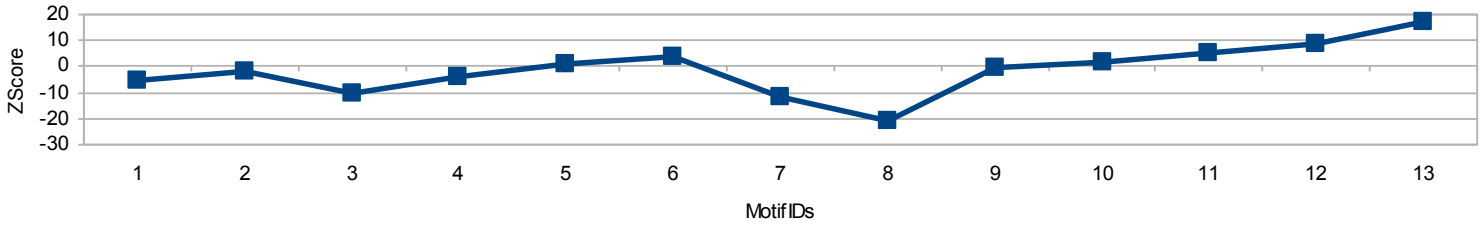
Digital s208



PLD s820



Digital s420



Aircraft

- Curiosity 2. (why are MSP of systems from a same family correlated)

Motif Significance Correlation

How to compare X_i across 2 systems of different sizes?

Normalized X_i to get Motif Significance Profile MSP Vector, $Y_i = X_i / |\mathbf{X}|$

Digital Fractional Multiplier s208

[1.64, 1.64, -7.43, 0, 0, 0, -1.64, 9.11, 0, 0 , 0, 0, 0] → **X**

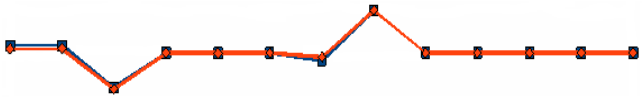
[0.14, 0.14, -0.61, 0, 0, 0, -0.14, 0.75, 0, 0 , 0, 0, 0] → **Y**

Ideas related to Motif Significance Profile Correlatio

Motif Significance Profile Vectors Y_i

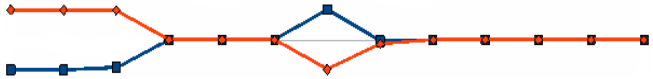
- System1 [0.08, 0.08, **-0.40**, 0, 0, 0, -0.08, **0.49**, 0, 0, 0, 0, 0]
- System2 [0.04, 0.04, **-0.42**, 0, 0, 0, -0.04, **0.49**, 0, 0, 0, 0, 0]

+0.99



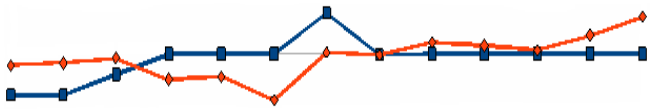
- System3 [**-0.3, -0.3, -0.3,** 0, 0, 0, **0.3**, -0.01, 0, 0, 0, 0, 0]
- System4 [**0.3, 0.3, 0.3**, 0, 0, 0,**-0.3**, -0.04, 0, 0, 0, 0, 0]

-0.98



- System5 [-0.3, -0.3, -0.17, 0, 0, 0, 0.3, -0.01, 0, 0, 0, 0, 0]
- System6 [-0.1, -0.1, 0, 0, -0.2, -0.4, 0.1, 0, 0, 0.1, 0, 0.2, 0.3]

+0.01



Correlation of Y_i of one system w.r.t another → +1 to -1

32 Engineering Systems

System no	System Name
S1	Apword (word processor)
S2	Linux (OS)
S3	Aircraft Engine
S4	ALU (c7552)
S5	Forward logic chips (s13207)
S6	ALU (74181)
S7	ECAT (c1355)
S8	Forward logic chips (s9234)
S9	Refrigerator
S10	Traffic control system (s420)
S11	ECAT (c499)
S12	Traffic control system (s382)
S13	ALU (c880)
S14	Digital Fractional Multiplier (s838)
S15	ECAT (c1908)
S16	Traffic control system (s400)

System no	System Name
S17	PLD (s832)
S18	Xmms (Music player)
S19	Forward logic chips (s38584)
S20	Digital Fractional Multiplier (s420)
S21	PLD (s641)
S22	Traffic control system (s562)
S23	Robot
S24	Vtk (Display programme)
S25	PLD (s832)
S26	Digital Fractional Multiplier (s208)
S27	Forward logic chips (s15850)
S28	Mysql (Database)
S29	Forward logic chips (s38417)
S30	PLD (s713)
S31	ALU (c3540)
S32	ALU (c2670)

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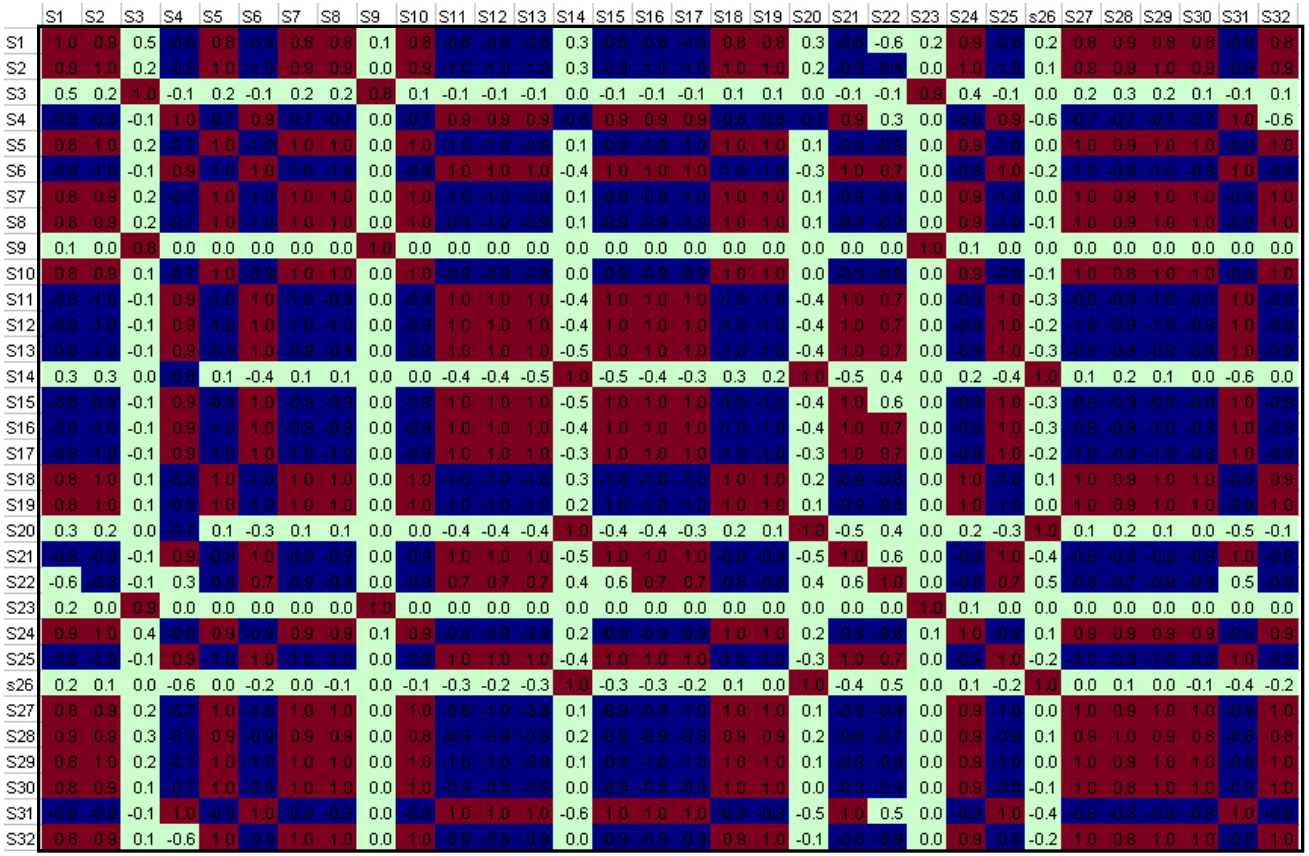
S28	Mysql (Database)
S29	Forward logic chips (s38417)
S30	PLD (s713)
S31	ALU (c3540)
S32	ALU (c2670)

Correlation Matrix - Significance Profile Vector



	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24	S25	s26	S27	S28	S29	S30	S31	S32
S1	1.0	0.9	0.5	-0.8	0.8	-0.9	0.8	0.8	0.1	0.8	-0.8	-0.8	-0.8	0.3	-0.8	-0.8	-0.8	0.8	0.8	0.3	-0.8	-0.6	0.2	0.9	-0.9	0.2	0.8	0.9	0.8	0.8	-0.8	0.8
S2	0.9	1.0	0.2	-0.8	1.0	-1.0	0.9	0.9	0.0	0.9	-1.0	-1.0	-1.0	0.3	-0.9	-1.0	-1.0	1.0	1.0	0.2	-0.9	-0.8	0.0	1.0	-1.0	0.1	0.9	0.9	1.0	0.9	-0.9	0.9
S3	0.5	0.2	1.0	-0.1	0.2	-0.1	0.2	0.2	0.8	0.1	-0.1	-0.1	-0.1	0.0	-0.1	-0.1	-0.1	0.1	0.1	0.0	-0.1	-0.1	0.9	0.4	-0.1	0.0	0.2	0.3	0.2	0.1	-0.1	0.1
S4	-0.8	-0.8	-0.1	1.0	-0.7	0.9	-0.7	-0.7	0.0	-0.7	0.9	0.9	0.9	-0.8	0.9	0.9	0.9	-0.8	-0.8	-0.7	0.9	0.3	0.0	-0.8	0.9	-0.6	-0.7	-0.7	-0.7	-0.7	1.0	-0.6
S5	0.8	1.0	0.2	-0.7	1.0	-1.0	1.0	1.0	0.0	1.0	-1.0	-1.0	-0.9	0.1	-0.9	-1.0	-1.0	1.0	1.0	0.1	-0.9	-0.9	0.0	0.9	-1.0	0.0	1.0	0.9	1.0	1.0	-0.9	1.0
S6	-0.9	-1.0	-0.1	0.9	-1.0	1.0	-1.0	-1.0	0.0	-0.9	1.0	1.0	1.0	-0.4	1.0	1.0	1.0	-1.0	-1.0	-0.3	1.0	0.7	0.0	-0.9	1.0	-0.2	-1.0	-0.9	-1.0	-0.9	1.0	-0.9
S7	0.8	0.9	0.2	-0.7	1.0	-1.0	1.0	1.0	0.0	1.0	-1.0	-1.0	-0.9	0.1	-0.9	-0.9	-1.0	1.0	1.0	0.1	-0.9	-0.9	0.0	0.9	-1.0	0.0	1.0	0.9	1.0	1.0	-0.9	1.0
S8	0.8	0.9	0.2	-0.7	1.0	-1.0	1.0	1.0	0.0	1.0	-0.9	-1.0	-0.9	0.1	-0.9	-0.9	-1.0	1.0	1.0	0.1	-0.9	-0.9	0.0	0.9	-1.0	-0.1	1.0	0.9	1.0	1.0	-0.9	1.0
S9	0.1	0.0	0.8	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S10	0.8	0.9	0.1	-0.7	1.0	-0.9	1.0	1.0	0.0	1.0	-0.9	-0.9	-0.9	0.0	-0.9	-0.9	-0.9	1.0	1.0	0.0	-0.9	-0.9	0.0	0.9	-0.9	-0.1	1.0	0.8	1.0	1.0	-0.8	1.0
S11	-0.8	-1.0	-0.1	0.9	-1.0	1.0	-1.0	-0.9	0.0	-0.9	1.0	1.0	1.0	-0.4	1.0	1.0	1.0	-1.0	-1.0	-0.4	1.0	0.7	0.0	-0.9	1.0	-0.3	-0.9	-0.9	-1.0	-0.9	1.0	-0.9
S12	-0.8	-1.0	-0.1	0.9	-1.0	1.0	-1.0	-1.0	0.0	-0.9	1.0	1.0	1.0	-0.4	1.0	1.0	1.0	-1.0	-1.0	-0.4	1.0	0.7	0.0	-0.9	1.0	-0.2	-1.0	-0.9	-1.0	-0.9	1.0	-0.9
S13	-0.8	-1.0	-0.1	0.9	-0.9	1.0	-0.9	-0.9	0.0	-0.9	1.0	1.0	1.0	-0.5	1.0	1.0	1.0	-1.0	-1.0	-0.4	1.0	0.7	0.0	-0.9	1.0	-0.3	-0.9	-0.9	-0.9	-0.9	1.0	-0.9
S14	0.3	0.3	0.0	-0.6	0.1	-0.4	0.1	0.1	0.0	0.0	-0.4	-0.4	-0.5	1.0	-0.5	-0.4	-0.3	0.3	0.2	1.0	-0.5	0.4	0.0	0.2	-0.4	1.0	0.1	0.2	0.1	0.0	-0.6	0.0
S15	-0.8	-0.9	-0.1	0.9	-0.9	1.0	-0.9	-0.9	0.0	-0.9	1.0	1.0	1.0	-0.5	1.0	1.0	1.0	-1.0	-1.0	-0.4	1.0	0.6	0.0	-0.9	1.0	-0.3	-0.9	-0.9	-0.9	-0.9	1.0	-0.9
S16	-0.8	-1.0	-0.1	0.9	-1.0	1.0	-0.9	-0.9	0.0	-0.9	1.0	1.0	1.0	-0.4	1.0	1.0	1.0	-1.0	-1.0	-0.4	1.0	0.7	0.0	-0.9	1.0	-0.3	-0.9	-0.9	-1.0	-0.9	1.0	-0.9
S17	-0.8	-1.0	-0.1	0.9	-1.0	1.0	-1.0	-1.0	0.0	-0.9	1.0	1.0	1.0	-0.3	1.0	1.0	1.0	-1.0	-1.0	-0.3	1.0	0.7	0.0	-0.9	1.0	-0.2	-1.0	-0.9	-1.0	-0.9	1.0	-0.9
S18	0.8	1.0	0.1	-0.8	1.0	-1.0	1.0	1.0	0.0	1.0	-1.0	-1.0	-1.0	0.3	-1.0	-1.0	-1.0	1.0	1.0	0.2	-0.9	-0.8	0.0	1.0	-1.0	0.1	1.0	0.9	1.0	1.0	-0.9	0.9
S19	0.8	1.0	0.1	-0.8	1.0	-1.0	1.0	1.0	0.0	1.0	-1.0	-1.0	-1.0	0.2	-1.0	-1.0	-1.0	1.0	1.0	0.1	-0.9	-0.8	0.0	1.0	-1.0	0.0	1.0	0.9	1.0	1.0	-0.9	1.0
S20	0.3	0.2	0.0	-0.7	0.1	-0.3	0.1	0.1	0.0	0.0	-0.4	-0.4	-0.4	1.0	-0.4	-0.4	-0.3	0.2	0.1	1.0	-0.5	0.4	0.0	0.2	-0.3	1.0	0.1	0.2	0.1	0.0	-0.5	-0.1
S21	-0.8	-0.9	-0.1	0.9	-0.9	1.0	-0.9	-0.9	0.0	-0.9	1.0	1.0	1.0	-0.5	1.0	1.0	1.0	-0.9	-0.9	-0.5	1.0	0.6	0.0	-0.9	1.0	-0.4	-0.9	-0.8	-0.9	-0.9	1.0	-0.8
S22	-0.6	-0.8	-0.1	0.3	-0.9	0.7	-0.9	-0.9	0.0	-0.9	0.7	0.7	0.7	0.4	0.6	0.7	0.7	-0.8	-0.8	0.4	0.6	1.0	0.0	-0.8	0.7	0.5	-0.9	-0.7	-0.9	-0.8	0.5	-0.9
S23	0.2	0.0	0.9	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S24	0.9	1.0	0.4	-0.8	0.9	-0.9	0.9	0.9	0.1	0.9	-0.9	-0.9	-0.9	0.2	-0.9	-0.9	-0.9	1.0	1.0	0.2	-0.9	-0.8	0.1	1.0	-0.9	0.1	0.9	0.9	0.9	0.9	-0.9	0.9
S25	-0.8	-1.0	-0.1	0.9	-1.0	1.0	-1.0	-1.0	0.0	-0.9	1.0	1.0	1.0	-0.4	1.0	1.0	1.0	-1.0	-1.0	-0.3	1.0	0.7	0.0	-0.9	1.0	-0.2	-1.0	-0.9	-1.0	-0.9	1.0	-0.9
s26	0.2	0.1	0.0	-0.6	0.0	-0.2	0.0	-0.1	0.0	-0.1	-0.3	-0.2	-0.3	1.0	-0.3	-0.3	-0.2	0.1	0.0	1.0	-0.4	0.5	0.0	0.1	-0.2	1.0	0.0	0.1	0.0	-0.1	-0.4	-0.2
S27	0.8	0.9	0.2	-0.7	1.0	-1.0	1.0	1.0	0.0	1.0	-0.9	-1.0	-0.9	0.1	-0.9	-0.9	-1.0	1.0	1.0	0.1	-0.9	-0.9	0.0	0.9	-1.0	0.0	1.0	0.9	1.0	1.0	-0.9	1.0
S28	0.9	0.9	0.3	-0.7	0.9	-0.9	0.9	0.9	0.0	0.8	-0.9	-0.9	-0.9	0.2	-0.9	-0.9	-0.9	0.9	0.9	0.2	-0.8	-0.7	0.0	0.9	-0.9	0.1	0.9	1.0	0.9	0.8	-0.8	0.8
S29	0.8	1.0	0.2	-0.7	1.0	-1.0	1.0	1.0	0.0	1.0	-1.0	-1.0	-0.9	0.1	-0.9	-1.0	-1.0	1.0	1.0	0.1	-0.9	-0.9	0.0	0.9	-1.0	0.0	1.0	0.9	1.0	1.0	-0.9	1.0
S30	0.8	0.9	0.1	-0.7	1.0	-0.9	1.0	1.0	0.0	1.0	-0.9	-0.9	-0.9	0.0	-0.9	-0.9	-0.9	1.0	1.0	0.0	-0.9	-0.9	0.0	0.9	-0.9	-0.1	1.0	0.8	1.0	1.0	-0.8	1.0
S31	-0.8	-0.9	-0.1	1.0	-0.9	1.0	-0.9	-0.9	0.0	-0.8	1.0	1.0	1.0	-0.6	1.0	1.0	1.0	-0.9	-0.9	-0.5	1.0	0.5	0.0	-0.9	1.0	-0.4	-0.9	-0.8	-0.9	-0.8	1.0	-0.8
S32	0.8	0.9	0.1	-0.6	1.0	-0.9	1.0	1.0	0.0	1.0	-0.9	-0.9	-0.9	0.0	-0.9	-0.9	-0.9	0.9	1.0	-0.1	-0.8	-0.9	0.0	0.9	-0.9	-0.2	1.0	0.8	1.0	1.0	-0.8	1.0

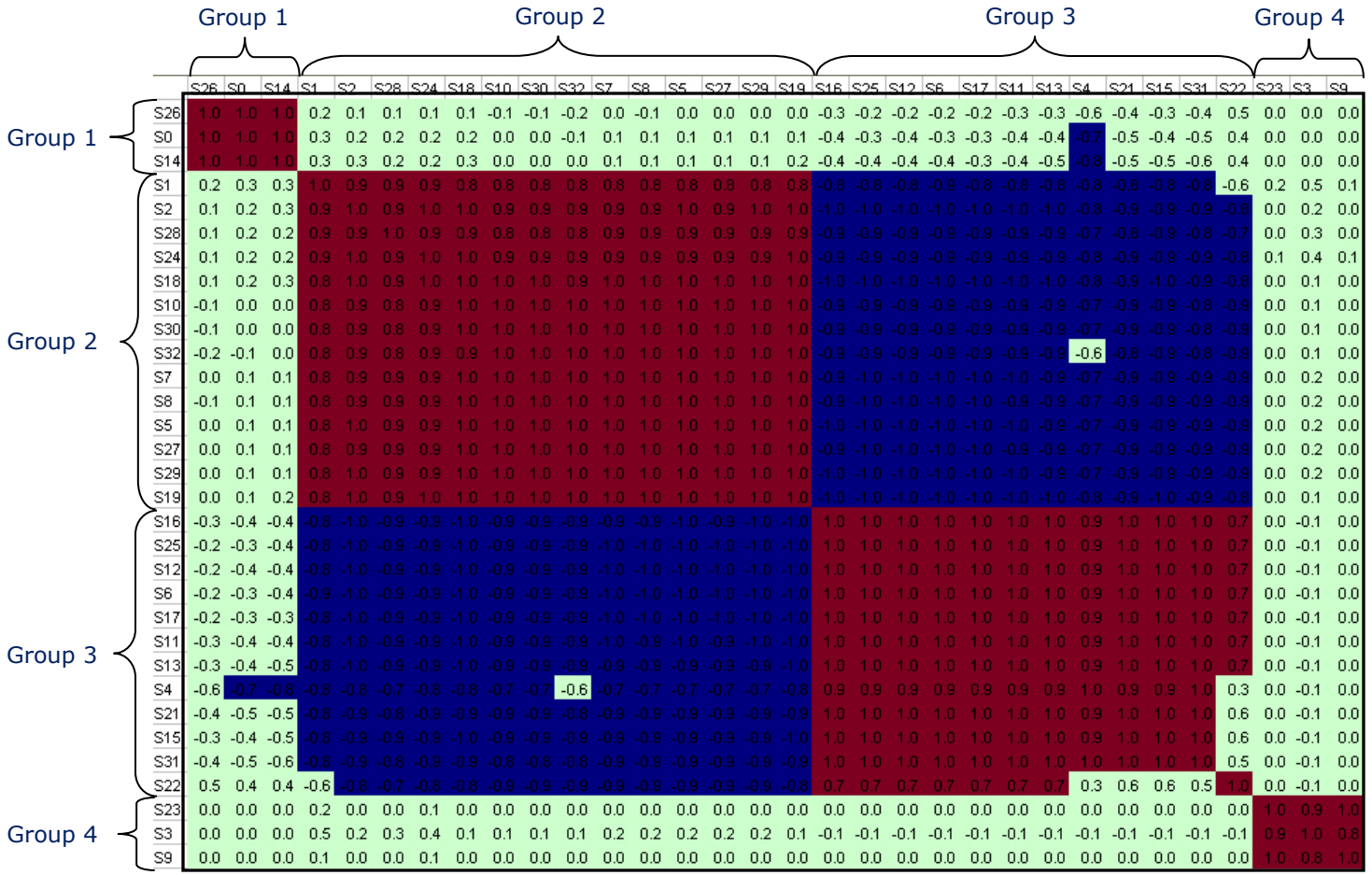
Legend

+0.65 ≤ Correlation coefficient ≤ +1.00, Positively correlated

- 0.65 < Correlation coefficient < +0.65, Weak or no correlation

- 1.0 ≤ Correlation coefficient ≤ -0.65, Negatively correlated

Correlation Matrix - Significance Profile Vector



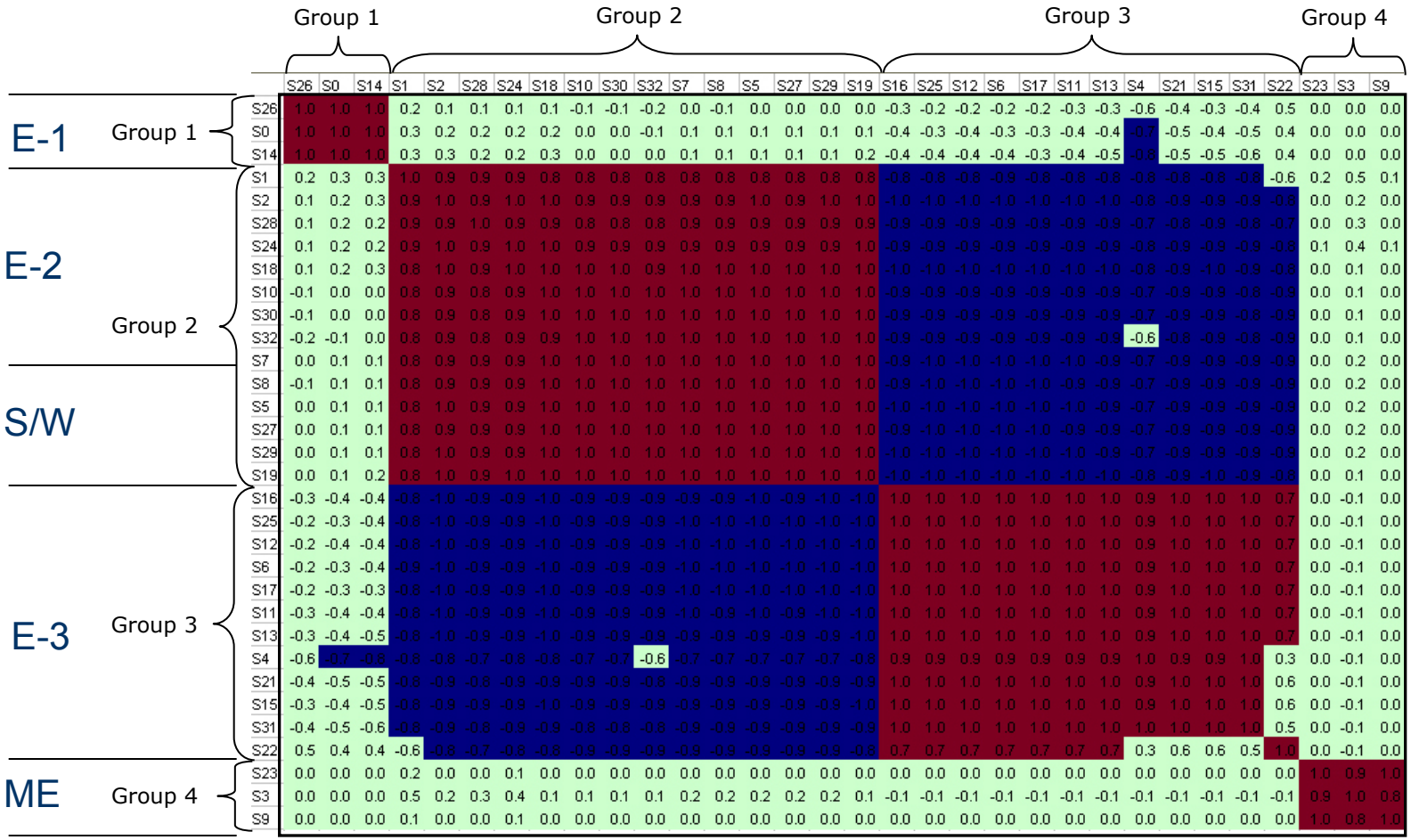
Legend

+0.65 ≤ Correlation coefficient ≤ +1.00, Positively correlated

- 0.65 < Correlation coefficient < +0.65, Weak or no correlation

- 1.0 ≤ Correlation coefficient ≤ -0.65, Negatively correlated

Correlation Matrix - Significance Profile Vector



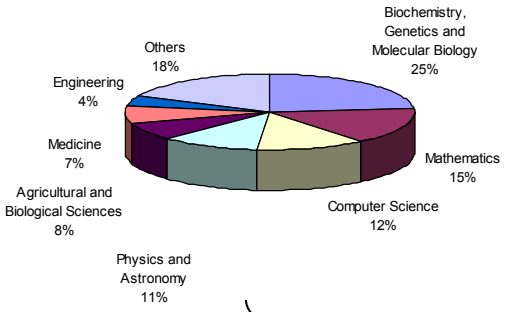
Group 1 – Electrical Systems 1
Group 2 – Software Systems, Electrical Systems 2
Group 3 – Electrical Systems 3
Group 4 – Mechanical System

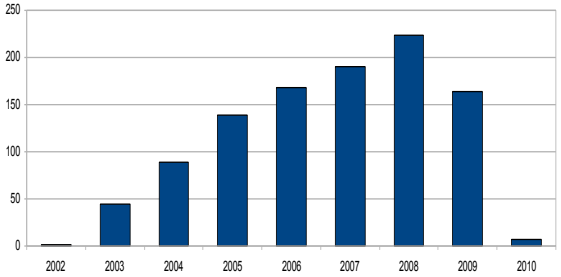
Curiosities !

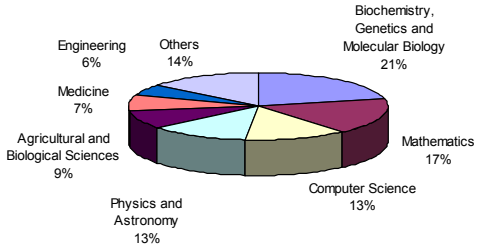
#1 Why are some motifs over(under) – represented in Engineering Systems?

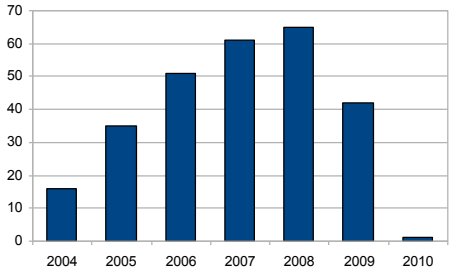
#2 Why are Motif Significance Profiles of systems within the same family correlated?

Motif & Motif Significance Profile - Literature Citatio









Network motifs: Simple building blocks of complex networks

Milo R et al

Science,2002

1027

Curiosity #1

Curiosity #2

Superfamilies of Evolved and DesignedNetworks

Milo R et al

Science, 2004

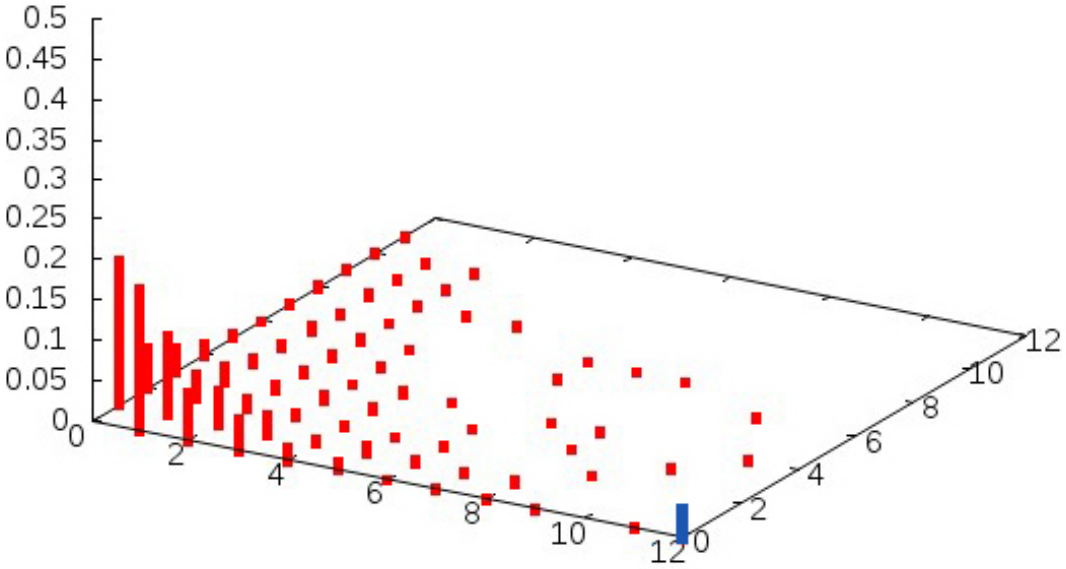
271

Classification of Systems from Component Characteristics

?

Why are MSPs co-related?

- Node characteristics; in-degree, out-degree of nodes
- NCP - Matrix of elements C_{ij} (i, j = 0 to 12)
- Total count of nodes with in-degree = i and out-degree = j present in the system normalized by N



How do node Characteristic Profiles across systems look?

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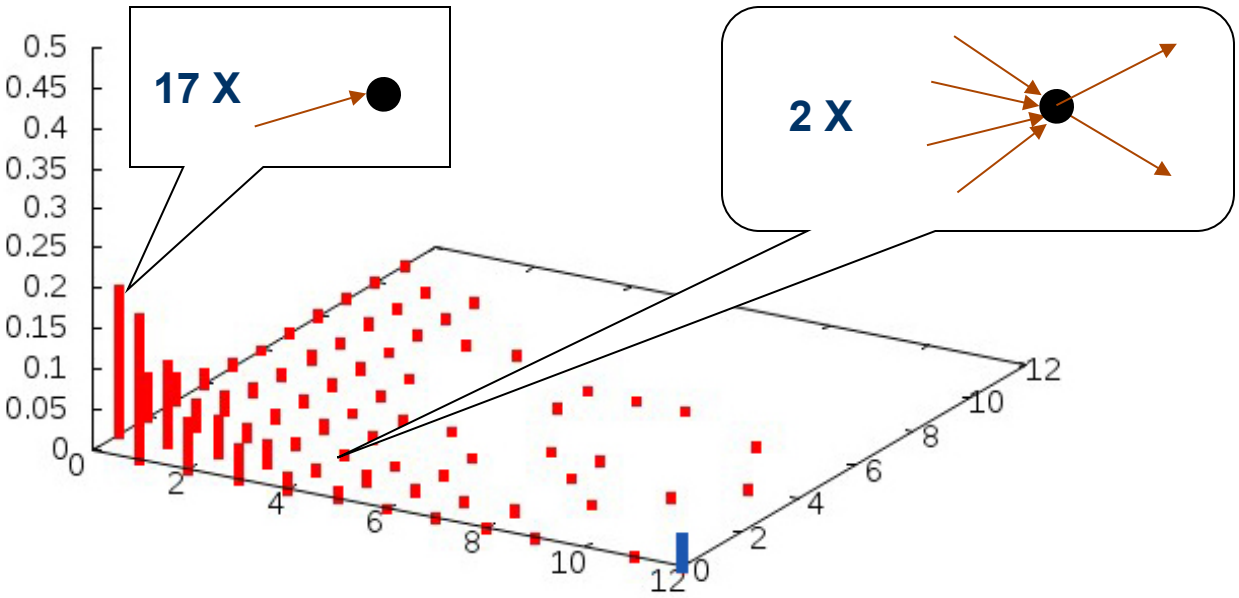

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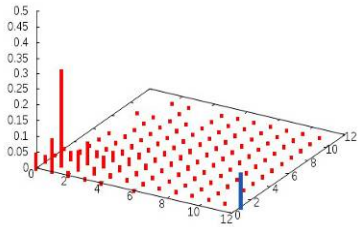
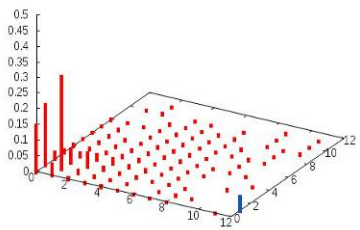
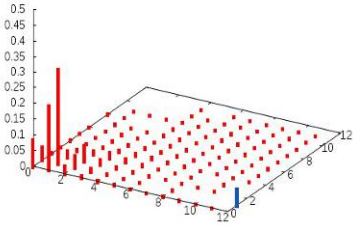


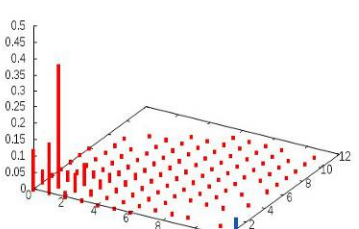
English



Japanese

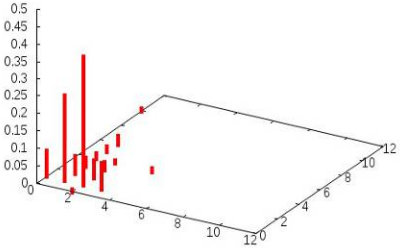


French

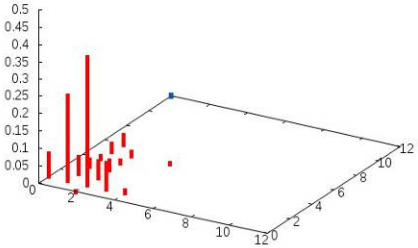


Spanish

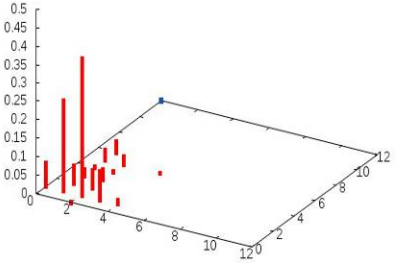
Language



Digital s208



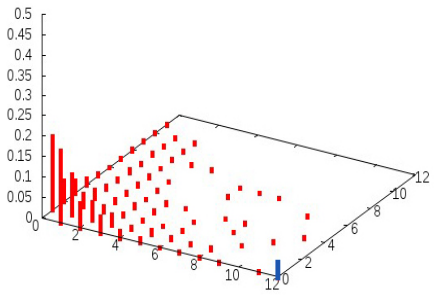
Digital s420



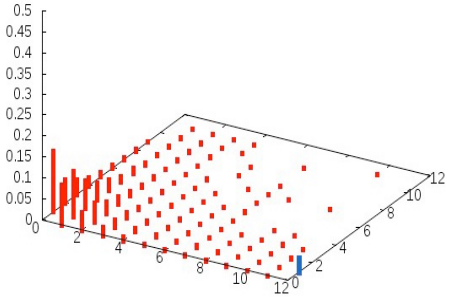
Digital s208

Digital Systems

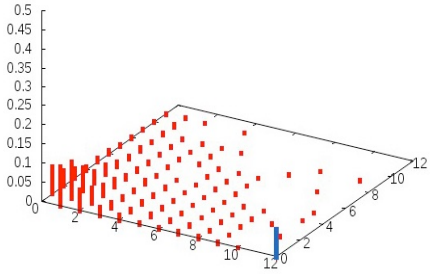
Why are MSPs co-related?



Xmms

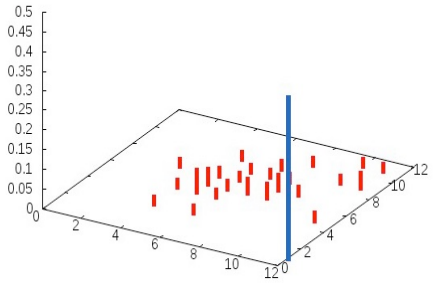


Linux

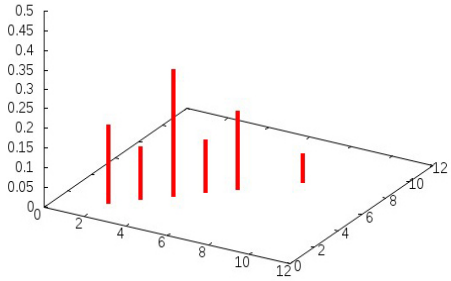


Mysql

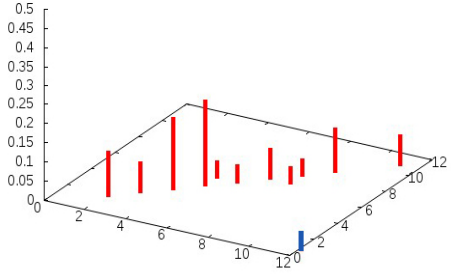
Software Systems



Aircraft



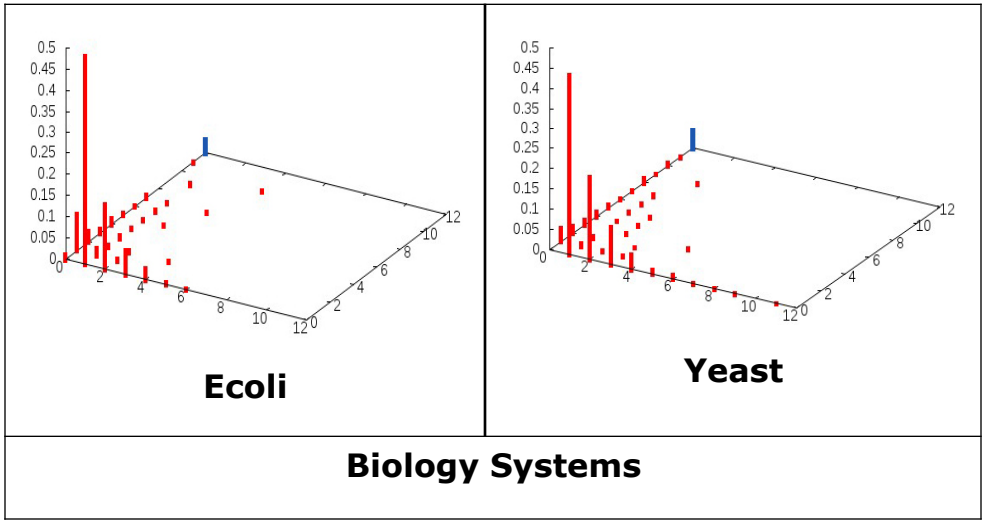
Climate



Robot

Mechanical Systems

Why are MSPs co-related?



Conclusion

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- Occurrence of over(under) represented motifs - remains to be a curiosity

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- Why are MSPs of systems within the same family same - Explained
- Occurrence of over(under) represented motifs - remains to be a curiosity (explained in our research very recently)
- Why is degree distribution of systems within the same family same – remains to be a curiosity still!

Computational Aspects

- Code for finding motifs, MSP, NCP developed as part of our work
- Erlang, Shell scripting & Statistical R
- CASMot - distributed framework for motif related analysis based on 'map-reduce' distributed computing
- Computations required to generate data to create MSP of 32 systems took roughly 950 hrs (approximately 40 days) using one eight core Itanium CPU having 16GB RAM

Thank you