ECE 454/544: Fault-Tolerant Computing & Reliability Engineering

Lecture #18 –

Trust Sensitivity Analysis for Social Networks

Instructor: Dr. Liudong Xing

Fall 2022

Administrative Issues
(Nov. 28, Monday)

- Last lecture on Wednesday (Nov. 30): **Final Review**
- Class Project
  - Final report due by **Nov. 30, Wednesday**
  - Presentation slides due by **Dec. 5, Monday**
  - Please check out the Report, Presentation Guidelines for requirements

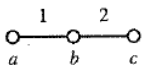
Slot	Dec. 5 (Mon)	Slot	Dec. 7 (Wed)
1	Team 3	4	Team 1
2	Team 2	5	Team 4
3	Team 5	6	Team 6

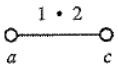
25 minutes per presentation

Review of Lecture#17

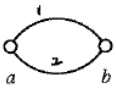
- Three kinds of network reliability: G=(V, E)
  - Two-terminal reliability (terminal-pair): two given vertices can communicate
  - All-terminal reliability: operation requires each pair of vertices is able to communicate via at least one operational path
  - K-terminal reliability: operation requires a few vertices, a subset K of V, to communicate each other
- Evaluation approaches
  - State space enumeration method
  - Cut-set and tie-set method
  - **Graph transformation method**
  - Binary decision diagrams-based method

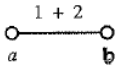
Transformation Method (Review)

(a) Series: 

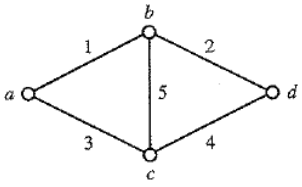
= 

$P_{ac} = P(1 \bullet 2)$

(b) Parallel: 

= 

$P_{ab} = P(1 + 2)$

(c) Decomposition (Edge Factoring): 

- Use series and parallel transformations first
- Resort to edge-factoring only when no more series or parallel transformations can be made!

Expand about 5: $R_{ad} = [P(5)Pr(G_1) + P(5')Pr(G_2)]$

$G_1 = G \cdot 5$ (G contract *edge 5*)
$G_2 = G\text{-}5$ (G delete *edge 5*)

Question: find R_{ad} given that each link fails independently with probability q=0.1?

Outline

- Social Networks and Trust
- Binary Decision Diagram (review)
- Two-Party Trust Sensitivity Analysis
- Examples

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References

- How to calculate trust between social network users?
- http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6347635&tag=1

- A Survey of Trust in Social Networks
- http://people.cs.vt.edu/~irchen/5984/pdf/Sherchan-acm-CSUR13.pdf

- Trust evaluation on Facebook using multiple contexts
- http://ceur-ws.org/Vol-997/trum2013_paper_3.pdf

- A smartphone-based online social network trust evaluation system
- http://link.springer.com/article/10.1007%2Fs13278-013-0138-4

- Two-Party Trust Sensitivity Analysis for Social Networks
- http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6258211

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Social Network

- A conception of social science
  - Uses actors and relations in the forms of graphs to indicate the social relationships between individuals or groups or organizations
- Social network service (SNS)
  - Internet-based social network
  - Helps people to maintain their connections

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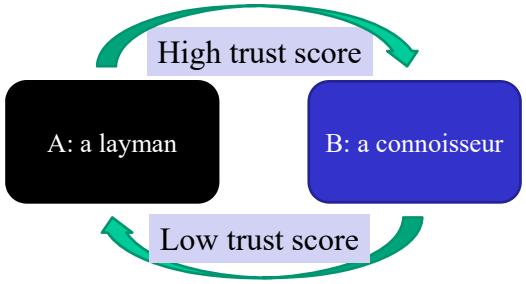
Trust Score

- Represents the relationship in social network
  - Asymmetry: the two parties usually trust each other differently
    - Critical for trust evaluation in social networks
  - For example: movie recommendation



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Trust Sensitivity

- Communication between two parties
  - Information could be passed through multiple intermediate parties
- Weakest link
  - Contributes the most to a particular two-party trust relationship
  - Potential hazard for delivering information flow
  - Critical to identify the weakest link

Trust Sensitivity Analysis

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Next …

- An application of the BDD-based network reliability analysis methods to trust analysis for social networks
- Perform trust sensitivity analysis

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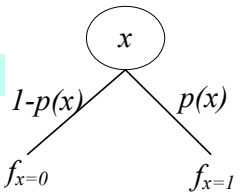
BDD Evaluation (review)

- BDD manipulation rules

$$g \Diamond h = ite(x, G_1, G_2) \Diamond ite(y, H_1, H_2)$$
$$= \begin{cases} ite(x, G_1 \Diamond H_1, G_2 \Diamond H_2) & index(x) = index(y) \\ ite(x, G_1 \Diamond h, G_2 \Diamond h) & index(x) < index(y) \\ ite(y, g \Diamond H_1, g \Diamond H_2) & index(x) > index(y) \end{cases}$$

- Evaluation algorithm

$$\Pr(f) = p(x) \cdot \Pr(F_1) + (1 - p(x)) \cdot \Pr(F_2)$$



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Social Network Modeling

- Modeled using a probabilistic graph $G(V, E)$
- A set V of nodes
  - People, parties, organizations
- A set E of directed links (also called ties or connections)
  - Represents direct trust relationship between two nodes
  - Characterized by a trust score or trust rating or trust probability (Trust can be non-identical in both directions of a relationship)

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Three Trust Concepts

Two-party trust	All-party trust	*K*-party trust
• Trust relationship between two particular parties	• Trust relationship between all parties	• Trust relationship between a subset of *K* parties

- The following only focuses on the two-party trust sensitivity analysis

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Example: Birnbaum's Measure

- A reliability sensitivity measure
  - Partial derivative of the two-party trust probability between source *S* and sink *T*, denoted by *Trust*(*S, T*)

$$I_{BM}(i) = \partial Trust(S,T) / \partial p(e_i)$$

  - $p(e_i)$: link trust score

- BDD-based method can be applied to evaluated *Trust*(*S, T*)

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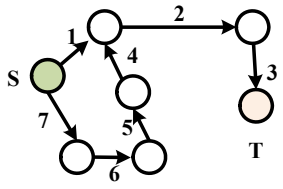
BDD-Based Method – Step 1

- Step 1: Order the social network links using a variable ordering heuristic
  - Starting from the source node, traverse the graph to search a path that can reach the sink node
  - Put all links of the selected path into the queue
  - Jump back from the sink nodes along the path to search for an alternative path



$e_1 < e_2 < e_3 < e_7 < e_6 < e_5 < e_4$

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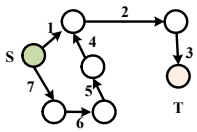
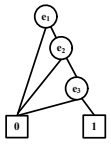
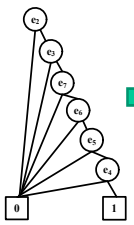
BDD-Based Method – Step 2

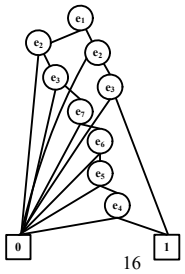
- Step 2: Generate the BDD model from the probabilistic graph of the social network using the ordering generated in Step 1
  - Traverse the graph to search all the paths to the sink node
  - Generate BDD for each path by performing logic AND operation on all the link variables involved in the path
  - Perform logic OR operation on all the path set BDD models





OR





Path 1: $\{e_1, e_2, e_3\}$

Path 2: $\{e_7, e_6, e_5, e_4, e_2, e_3\}$

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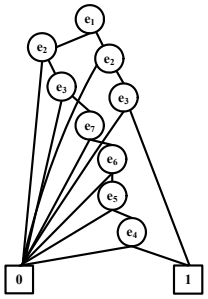
BDD-Based Method – Step 3

- Step 3: Evaluate *Trust*(*S, T*) recursively from the BDD obtained in Step 2
  - Manually, *Trust*(*S, T*) can be calculated as the sum of probabilities of all disjoint paths from the root to sink node "1"



Two disjoint paths:

$e_1 \rightarrow e_2 \rightarrow e_3$

$\neg e_1 \rightarrow e_2 \rightarrow e_3 \rightarrow e_7 \rightarrow e_6 \rightarrow e_5 \rightarrow e_4$

$$Trust(S,T) = p(e_1)\cdot p(e_2)\cdot p(e_3) + [1-p(e_1)]\cdot p(e_2)\cdot p(e_3)\cdot p(e_7)\cdot p(e_6)\cdot p(e_5)\cdot p(e_4)$$

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Sensitivity Evaluation

- Consider a BDD branch rooted at node *x* that represents a direct link in the social network
  - If a variable (a link) being considered: $e_i \neq x$

$$\frac{\partial \Pr(f)}{\partial p(e_i)} = p(x)\cdot\frac{\partial \Pr(F_1)}{\partial p(e_i)} + (1-p(x))\cdot\frac{\partial \Pr(F_2)}{\partial p(e_i)}$$

  - Otherwise, for $e_i = x$

$$\frac{\partial \Pr(f)}{\partial p(e_i)} = \Pr(F_1) - \Pr(F_2)$$

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Agenda

- Social Networks and Trust
- Binary Decision Diagram (review)
- Two-Party Trust Sensitivity Analysis
- **Examples**

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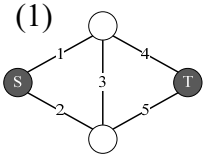
Example Social Networks

(1)



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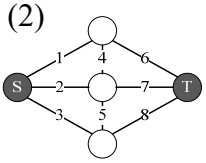

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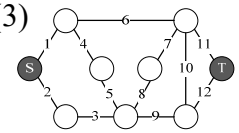

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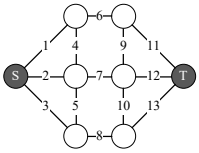

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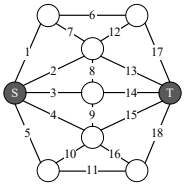

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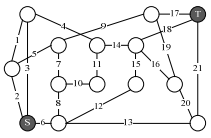
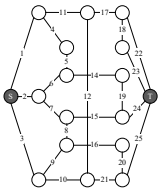


(7)



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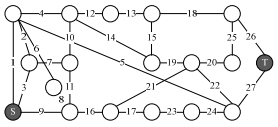

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Results using BM (trust score 0.7)

Link	Example Social Network Graphs							
	1	2	3	4	5	6	7	8
1	0.2982	0.113803	0.396036	0.113785	0.014131	0.102751	0.167017	0.116024
2	0.2982	0.117772	0.225487	0.117348	0.018697	0.110919	0.138155	0.034520
3	0.0882	0.113803	0.225487	0.113785	0.018591	0.040947	0.143780	0.075920
4	0.2982	0.037573	0.070293	0.044104	0.018697	0.112007	0.065619	0.047148
5	0.2982	0.037573	0.070293	0.044104	0.014131	0.208145	0.044503	0.179353
6	-	0.113803	0.247870	0.129464	0.005794	0.144855	0.055744	0.017668
7	-	0.117772	0.056528	0.143257	0.004287	0.054992	0.058728	0.028371
8	-	0.113803	0.056528	0.129464	0.007046	0.045898	0.039806	0.017668
9	-	-	0.146568	0.044104	0.007046	0.145357	0.048009	0.096968
10	-	-	0.070269	0.044104	0.004287	0.027169	0.071720	0.041112
11	-	-	0.269433	0.113785	0.005794	0.027169	0.074467	0.024746
12	-	-	0.223018	0.117348	0.004287	0.039088	0.044569	0.039388
13	-	-	-	0.113785	0.018697	0.099736	0.083188	0.039388
14	-	-	-	-	0.018591	0.103748	0.030185	0.055886
15	-	-	-	-	0.018697	0.039165	0.062148	0.044375
16	-	-	-	-	0.004287	0.038451	0.033687	0.079094
17	-	-	-	-	0.014131	0.121213	0.077553	0.020641
18	-	-	-	-	0.014131	0.134288	0.026589	0.108712
19	-	-	-	-	-	0.042764	0.030158	0.044438
20	-	-	-	-	-	0.034597	0.033689	0.063216
21	-	-	-	-	-	0.108683	0.053795	0.049470
22	-	-	-	-	-	-	0.060486	0.064052
23	-	-	-	-	-	-	0.062110	0.020641
24	-	-	-	-	-	-	0.105442	0.020639
25	-	-	-	-	-	-	0.098303	0.063215
26	-	-	-	-	-	-	-	0.239148
27	-	-	-	-	-	-	-	0.403625

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Results using CIF (trust score 0.7)

Link	Example Social Network Graphs							
	1	2	3	4	5	6	7	8
1	0.450998	0.456050	0.354557	0.272254	0.364070	0.178415	0.355004	0.146725
2	0.450998	0.471955	0.201871	0.280779	0.481713	0.192597	0.293657	0.043655
3	0.133394	0.456050	0.201871	0.272254	0.478980	0.071099	0.305612	0.096009
4	0.450998	0.150569	0.062931	0.105527	0.481713	0.194487	0.139476	0.047148
5	0.450998	0.150569	0.062931	0.105527	0.364070	0.361419	0.094593	0.226811
6	-	0.456050	0.221910	0.309767	0.149286	0.251524	0.118487	0.022343
7	-	0.471955	0.050608	0.342769	0.110444	0.095487	0.124829	0.035878
8	-	0.456050	0.050608	0.309767	0.181533	0.079697	0.084609	0.022343
9	-	-	0.131217	0.105527	0.181533	0.252396	0.102046	0.122626
10	-	-	0.062909	0.105527	0.110444	0.047176	0.152444	0.051991
11	-	-	0.241214	0.272254	0.149286	0.047176	0.158283	0.031294
12	-	-	0.199661	0.280779	0.110444	0.067872	0.094735	0.049811
13	-	-	-	0.272254	0.481713	0.173180	0.176820	0.049811
14	-	-	-	-	0.478980	0.180147	0.064161	0.070673
15	-	-	-	-	0.481713	0.068006	0.132099	0.056117
16	-	-	-	-	0.110444	0.066765	0.071604	0.100023
17	-	-	-	-	0.364070	0.210472	0.164842	0.026103
18	-	-	-	-	0.364070	0.233175	0.056517	0.137478
19	-	-	-	-	-	0.074255	0.064103	0.056196
20	-	-	-	-	-	0.060074	0.071607	0.079944
21	-	-	-	-	-	0.188716	0.114345	0.062560
22	-	-	-	-	-	-	0.128566	0.081001
23	-	-	-	-	-	-	0.132017	0.026103
24	-	-	-	-	-	-	0.224123	0.026101
25	-	-	-	-	-	-	0.208949	0.079942
26	-	-	-	-	-	-	-	0.302427
27	-	-	-	-	-	-	-	0.510427

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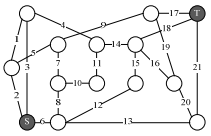
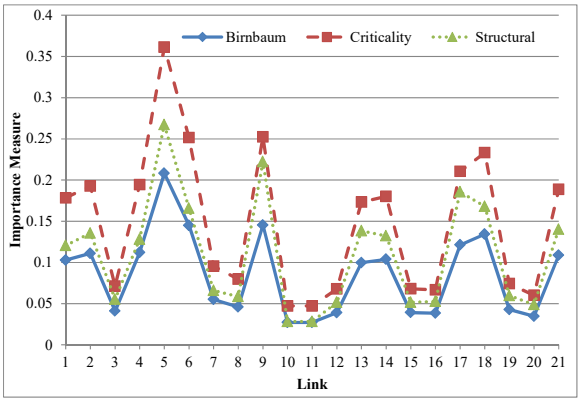
Results using SIM (trust score 0.7)

Link	Example Social Network Graphs							
	1	2	3	4	5	6	7	8
1	0.375	0.25	0.309082	0.194824	0.082855	0.120556	0.224137	0.178753
2	0.375	0.265625	0.152832	0.210938	0.135681	0.135639	0.165692	0.058518
3	0.125	0.25	0.152832	0.194824	0.134171	0.055267	0.176633	0.082596
4	0.375	0.09375	0.051270	0.086426	0.135681	0.128096	0.105472	0.058812
5	0.375	0.09375	0.051270	0.086426	0.082855	0.267191	0.058683	0.276980
6	-	0.25	0.250488	0.210938	0.043121	0.165672	0.075467	0.026757
7	-	0.265625	0.045410	0.248535	0.036346	0.065977	0.091273	0.032962
8	-	0.25	0.045410	0.210938	0.056854	0.058594	0.051191	0.026757
9	-	-	0.129395	0.086426	0.056854	0.222334	0.066384	0.102727
10	-	-	0.073730	0.086426	0.036346	0.028223	0.111529	0.044393
11	-	-	0.233887	0.194824	0.043121	0.028223	0.119120	0.033105
12	-	-	0.168457	0.210938	0.036346	0.051580	0.066175	0.033569
13	-	-	-	0.194824	0.135681	0.138420	0.128905	0.033569
14	-	-	-	-	0.134171	0.132196	0.042519	0.056487
15	-	-	-	-	0.135681	0.051661	0.103890	0.040002
16	-	-	-	-	0.036346	0.052589	0.044891	0.078899
17	-	-	-	-	0.082855	0.185572	0.123323	0.018097
18	-	-	-	-	0.082855	0.167999	0.047882	0.076740
19	-	-	-	-	-	0.059786	0.042490	0.044109
20	-	-	-	-	-	0.048906	0.044891	0.046215
21	-	-	-	-	-	0.140312	0.096241	0.059181
22	-	-	-	-	-	-	0.106978	0.072848
23	-	-	-	-	-	-	0.109464	0.018097
24	-	-	-	-	-	-	0.150807	0.018092
25	-	-	-	-	-	-	0.143450	0.046210
26	-	-	-	-	-	-	-	0.132477
27	-	-	-	-	-	-	-	0.376453

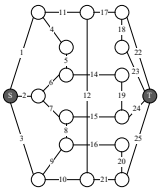
Results (#6)

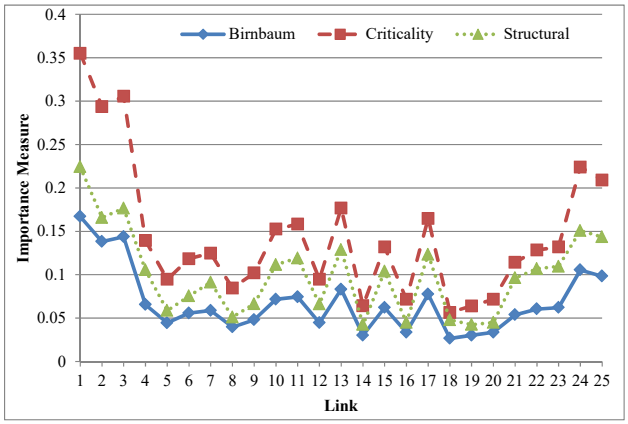




Link 5 contributes the most, and links 10 and 11 contribute the least to the trust relationship between *S* and *T*

Results (#7)





Link 1 contributes the most, and link 18 contributes the least to the trust relationship between *S* and *T*

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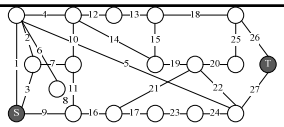
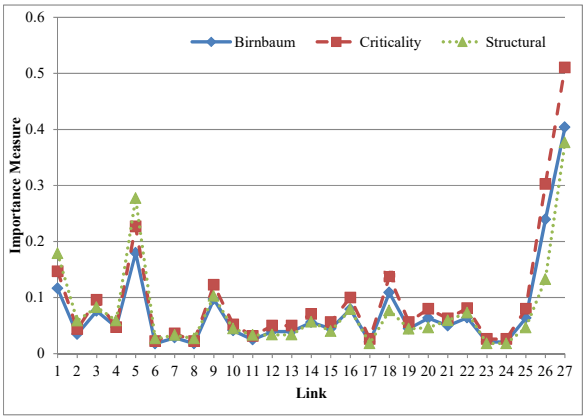
Results (#8)





Link 27 is the most important link, and links 6 and 8 are the least important ones with regard to the trust relationship between *S* and *T*

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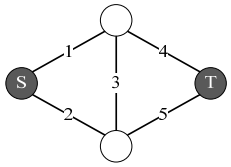
Graph 1 (Non-identical trust scores)

Link		Sensitivity Measures		
#	score	Birnbaum	CIF	SIM
1	0.2	0.0854	0.303483	0.375
2	0.9	0.7072	0.314144	0.375
3	0.7	0.0544	0.072495	0.125
4	0.3	0.1456	0.452736	0.375
5	0.8	0.7046	0.625977	0.375



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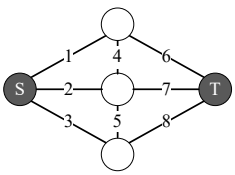
Graph 2 (Non-identical trust scores)

Link		Sensitivity Measures		
#	score	Birnbaum	CIF	SIM
1	0.2	0.071445	0.265301	0.25
2	0.9	0.208070	0.096580	0.265625
3	0.7	0.111533	0.155311	0.25
4	0.8	0.180515	0.167580	0.09375
5	0.8	0.085315	0.079202	0.09375
6	0.6	0.318066	0.590548	0.25
7	0.1	0.207098	0.865160	0.265625
8	0.6	0.416266	0.772875	0.25



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Things To Do

- Final report due by **Nov. 30, Wednesday**
- Presentation slides due by **Dec. 5, Monday**

- Please check out the Report, Presentation Guidelines for requirements