DESIGN STRUCTURE AND ITERATIVE RELEASE ANALYSIS OF SCIENTIFIC SOFTWARE

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Outline

- Objectives
- Methodology
- Experimental Results
- Iterative Release Comparison
- Release Cost Estimation
- Findings and future work

Scientific Research Software

- General-purpose Commercial Software
  - Employ formal methods from software engineering discipline
  - Well known problem domains
  - Trained engineers familiar with tested 'best-practices'
- Scientific Research Software
  - 'Proof-of-concept' code vs 'Large Scale simulation'
  - Designed by highly trained scientists
  - Focuses on narrow and highly specialized domain.

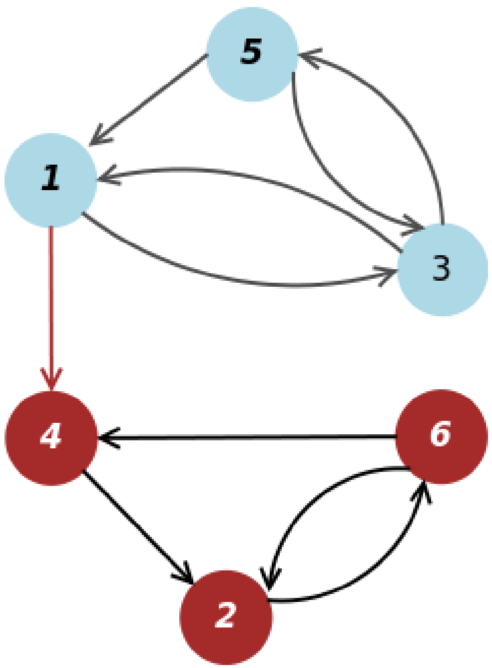
Objectives

- Study and analyze design structure of scientific software systems with suitable design structural metrics and DSM to investigate:
  - Modularity
  - Maintainability
  - Extensibility, etc
- In our research we have chosen the open source scientific computing software that focuses on below application domains:
  - AD (Automatic Differentiation)
  - LP (Linear Programming)
  - MIP (Mixed Integer Programming)

Modelling Dependencies with DSM

- DSM : Square matrix with identical row and column.
- DSM has been used to capture and analyze the dependencies of the software.
- Call graph extractor used to extract static source code dependencies.
- User defined functions are basic design elements.

Call graphs to DSM



		1	2	3	4	5	6
Vertex 1	1	X		X	X		
Vertex 2	2		X				X
Vertex 3	3	X		X		X	
Vertex 4	4		X		X		
Vertex 5	5	X		X		X	
Vertex 6	6		X		X		x

- Dependencies between two user defined functions are denoted by an off-diagonal mark in DSM.

Structural Metrics

- **Characteristic path length :**

$$l = \frac{\sum_{i \neq j} d_{ij}}{N(N-1)}$$

where d_{ij} : length of the shortest path connecting the nodes i and j

  - This provides us information regarding the efficiency of software

- **Clustering co-efficient:**

$$C = \frac{1}{N}\sum_{i=1}^{N} C_i$$

where $$C_i = \frac{2 * n_i}{k_i(k_i - 1)}$$

denotes C_i : the clustering co-efficient of node i
k_i : number of nodes i is adjacent to
n_i : actual number of edges between node i's adjacent nodes.

  - This provides us information regarding the modularity of the software

Structure Metrics (contd..)

- **Average nodal degree:** $$k = \frac{1}{N}\sum_{i=1}^{N} k_i$$

  where k_i : number of nodes adjacent to node i

  - This provides us information regarding the degree of dependencies of system elements.

- **Propagation cost:** $$\frac{1}{N}\sum_{i=1}^{N} p_i$$

  where p_i: number of nodes reachable from node i

  - This provides us information regarding the sensitivity of the system elements

- **Centrality measure:** An index that measures the centrality of a node by the number of shortest path in the graph containing that node.

  - This provide us information regarding the global information of software.

Experiments

- Experimental Environment
  - **Machine:** HP P6510 F
  - **Processor:** AMD Athlon X4 630 Quad Core processors
  - **Operating System:** Ubuntu 10.04
- We studied and analyzed the following 4 software tools:
  - **ADOL-C**: An AD software
  - **BCP:** A MIP software
  - **CppAD**: An AD
  - **DyLP :** A LP software

Partitioning the DSM

- Partitioning : Reordering of the DSM rows and columns so that new DSM contains minimum number of feedback marks.

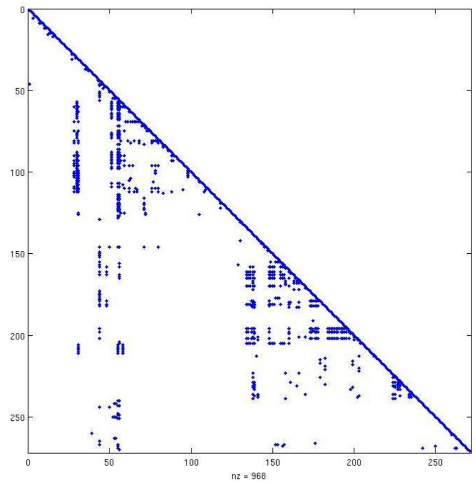
- Partitioned DSM allow us to identify
  - Sequential tasks
  - Parallel tasks
  - Iterative tasks.

- We used Tarzan's algorithm using sparse data structure.

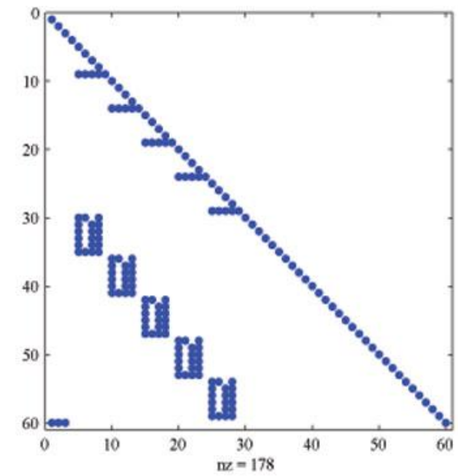
Matrix Name	# of vertices, N	# of components	Boost Timing (s)	Our Timing (s)
NotreDame	325729	231666	1.6812	0.318
amazon0601	403394	1588	11.08	2.418
StanfordBerkeley	683446	109238	22.568	3.80

Partitioned DSM

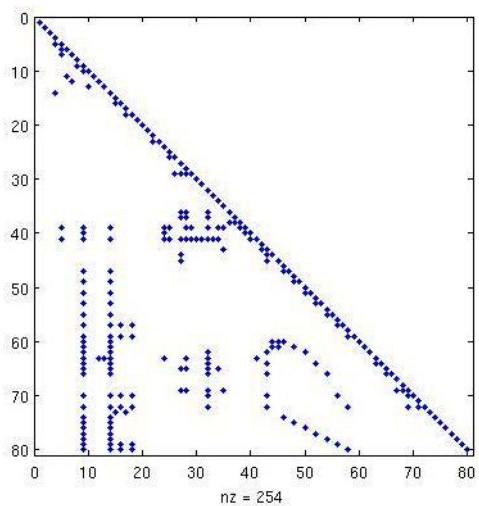
ADOL-C



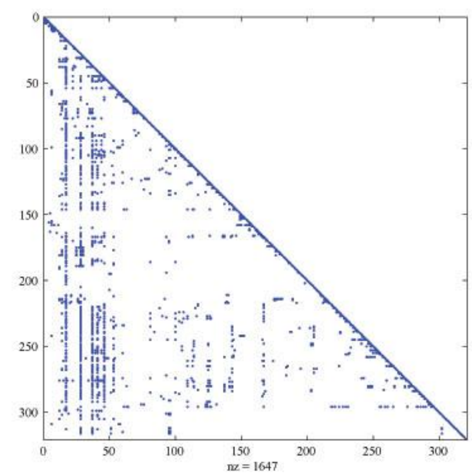
Bcp



CppAD



DyLP

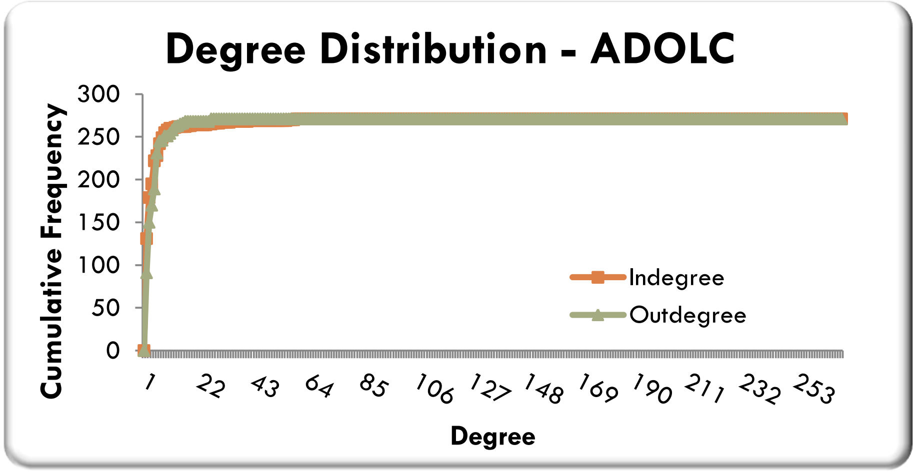


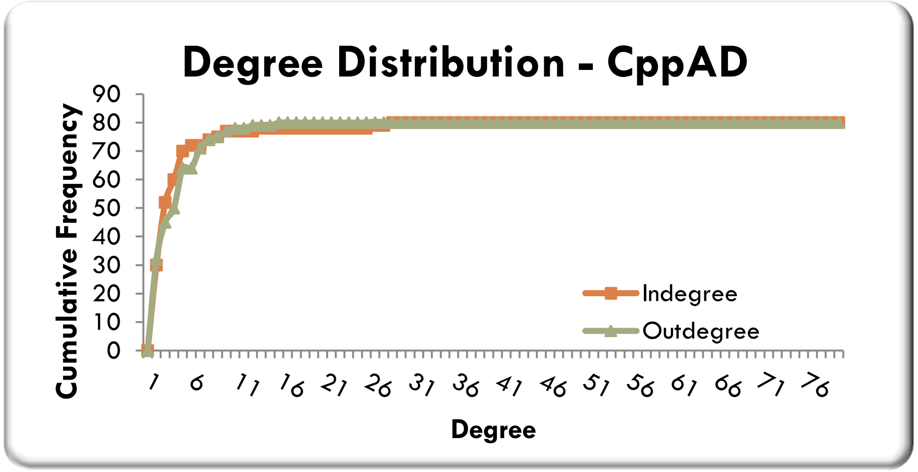
Structural Properties & Metrics

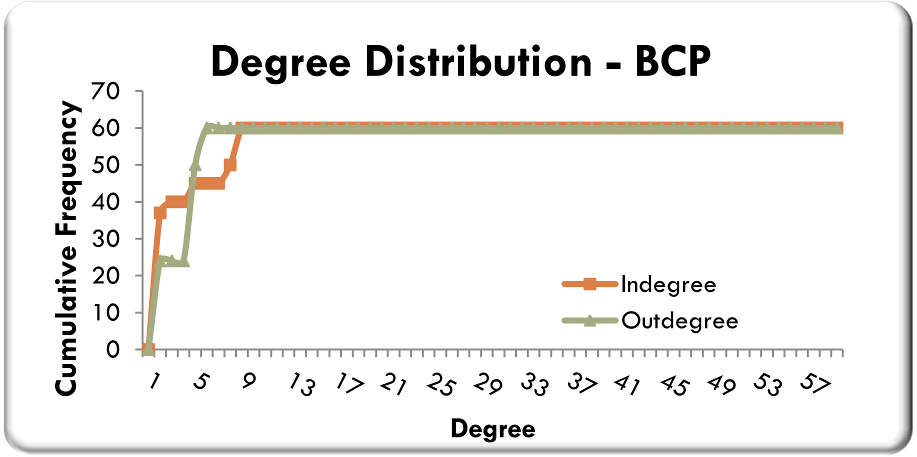
Software	Nodes		Directed Edges		Sparsity
	Files	User functions	Files	User functions	
ADOL-C	60	271	66	703	0.95 %
Bcp	45	60	29	118	3.33 %
CppAD	66	80	67	175	2.74 %
DyLP	51	315	333	1321	1.34 %

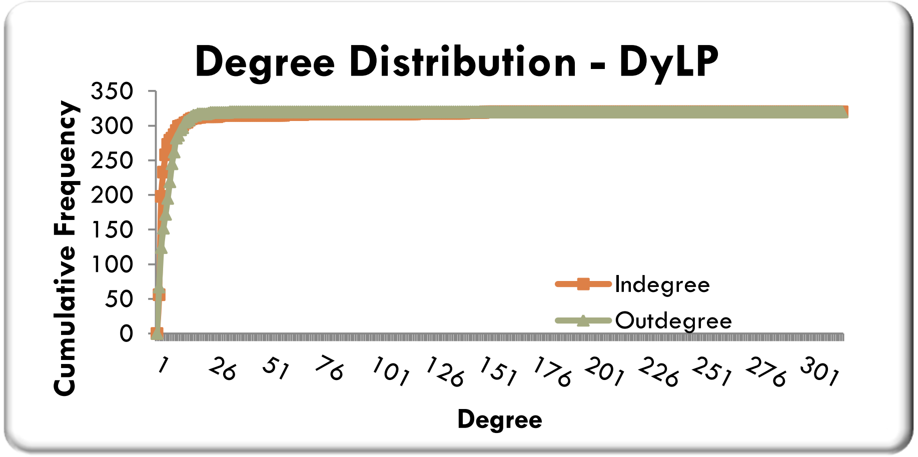
Software	Characteristic Path length, l	Clustering co-efficient, C	Nodal Degree	Propagation Cost (%)
ADOL- C	2.05005	0.080382	5.18819	3.41635
Bcp	0.264972	0	3.93333	4.94444
CppAD	2.37373	0.0342364	4.375	6.64062
DyLP	2.67967	0.245807	8.3873	5.17208

Degree Distribution









Power Law & Scale Free Networks

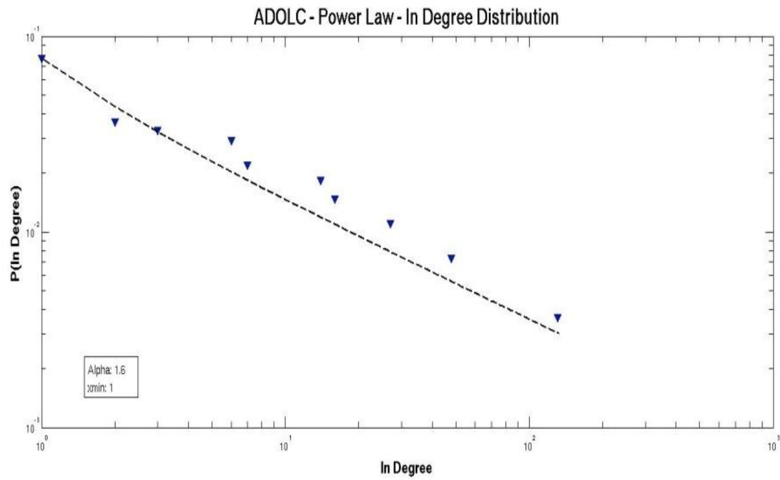
- Power Law: $$p(x) \propto x^{-\alpha}$$

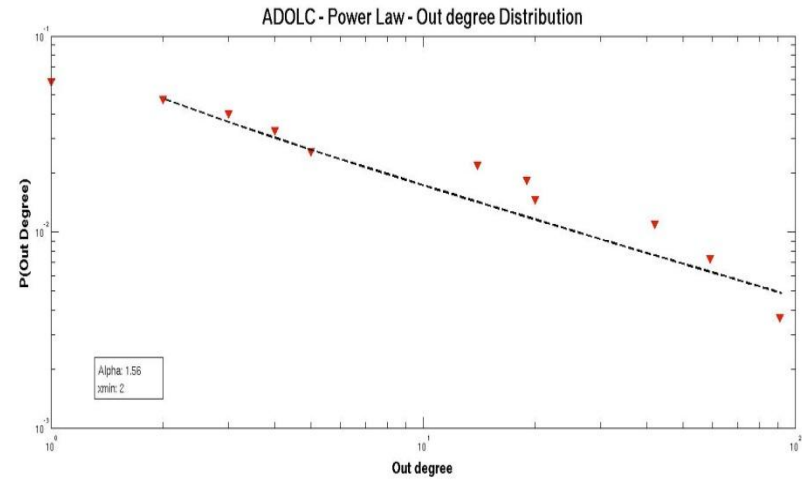
  Where α is the scaling factor

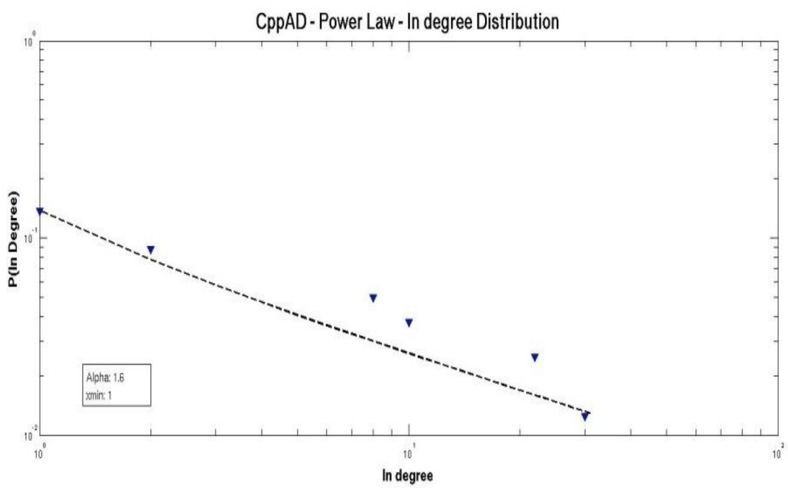
  Power law applies for values greater than $x_{\min}$

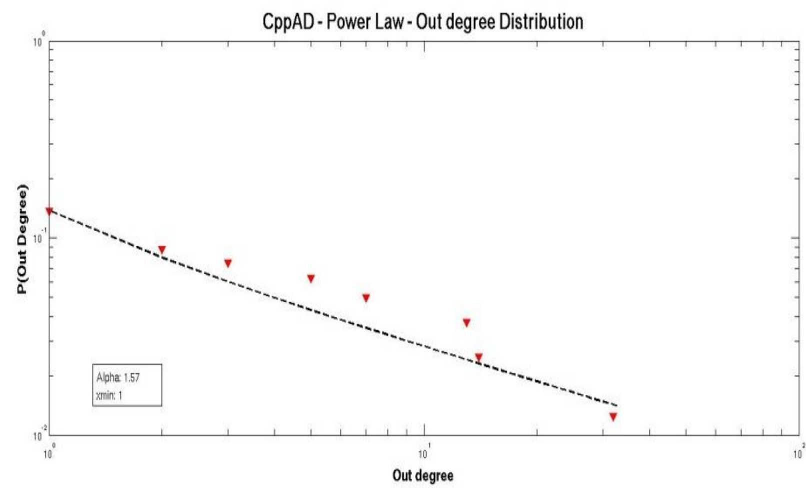
- Scale free networks: Networks with power law degree distribution.
- Scale free networks characteristics:
  - Contains Hubs
  - Network Robustness to failure

Power Law Analysis - Degree Distribution

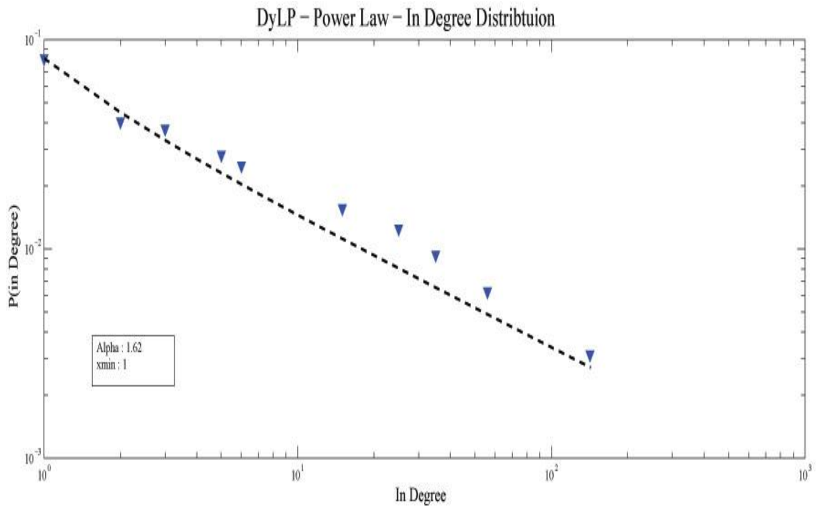


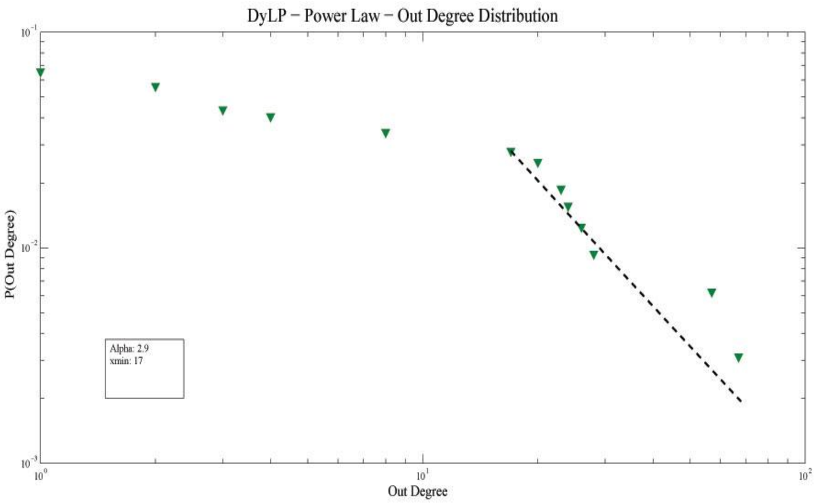






Power Law Analysis - Degree Distribution (contd)





	x_{min}	*a*	*p*
ADOLC – In degree	1	1.6	0.267
ADOLC – Out degree	2	1.56	0.286
CppAD – In degree	1	1.6	0.388
CppAD – Out degree	1	1.7	0.493
DyLP – In degree	1	1.62	0.10
DyLP – Out degree	17	2.9	0.12

Iterative Release Analysis

- New customer requirements necessitate iterative releases.
- Feature enhancement, improving computational efficiency, etc drives iterative release in scientific software.
- Iterative release analysis allows us to investigate the changes in structural properties and metrics of scientific software releases.

Iterative Release Analysis Results

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Software	Compared releases	Changes in Release	Maximum New Elements added	Change in Central function
ADOLC	10	1 major, 4 minor	116	Yes
Bcp	**7**	**No Change**	**0**	**No**
CppAD	10	1 major, 1 minor	33	No
DyLP	10	1 major, 2 minor	65	No

- ADOLC :

ADOLC Versions	Characteristic Path length, l	Clustering co-efficient, C	Nodal Degree	Number of Components	Propagation Cost (%)
V 1.9	3.36142	0.107767	6.55873	315	3.53238
V 1.10.2	3.25725	0.106083	6.48125	320	3.43262
V 2.1.2	2.04977	0.0803177	5.19557	271	3.42316
V 2.1.4	2.0611	0.0777237	5.13971	272	3.38452
V 2.1.12	2.20408	0.0803834	5.26236	263	3.58831
V 2.2.1	2.16312	0.0799071	5.21509	265	3.50303

Iterative Release Analysis Results(contd..)

- CppAD :

CppAD Version	Characteristic Path length, l	Clustering co-efficient, C	Nodal Degree	Number of Components	Propagation Cost (%)
V 110101.0	2.35228	0.0363174	4.31579	76	6.95983
V 110308	2.37373	0.0342364	4.375	80	6.64062
V 111103	2.44108	0.0265913	3.80583	103	9.6239

- DyLP

DyLP Version	Characteristic Path length, l	Clustering co-efficient, C	Nodal Degree	Number of Components	Propagation Cost (%)
V 1.3.0	2.67341	0.261488	8.18729	299	5.51112
V 1.4.0	2.6719	0.258967	8.22074	299	5.51784
V 1.5.0	2.67967	0.245807	8.3873	315	5.17208
V 1.7.0	2.63341	0.24186	8.29375	320	5.04883

Iterative Release Cost

- Total implementation cost of release *n*,

$$Tc_n = Ic_n + Rc_n$$

- Ic_n is the summation of the cost to implement all the new architectural element .
- We assumed implementation cost of each architectural element is 1.
- Release rework cost, Rc_n is calculated using:

$$Rc_n = \sum_{j=1}^{m} I[j] \times P_{n-1}$$

where

m : No. of new elements added

$I[j]$: No. of old version dependency these new element j have.

P_{n-1} : propagation cost of previous release n-1.

Release Cost Estimation

- ADOL-C :

Old Version	New Version	No. of New Elements	p_{n-1}	Ic_n	Rc_n	Tc_n
V1.9	V1.10.0	6	0.0353238	6	0.52986	**6.52986**
V1.10.0	V2.1.0	116	0.0343262	116	13.696	**129.696**
V2.1.0	V2.1.4	1	0.0342316	1	0.03423	**1.03423**
V2.1.4	V2.1.12	1	0.0338452	1	0.0338452	**1.0338452**
V2.1.12	V2.2.1	7	0.0358831	7	0.28707	**7.28707**

- CppAD:

Old Version	New Version	No. of New Elements	p_{n-1}	Ic_n	Rc_n	Tc_n
V 110101.0	V 110308	4	0.0695983	4	0.34799	**4.34799**
V 110308	V 111103	33	0.0664062	33	3.5859	**36.5859**

- DyLP:

Old Version	New Version	No. of New Elements	p_{n-1}	Ic_n	Rc_n	Tc_n
V 1.3.0	V 1.4.0	65	0.0551112	65	12.896	**77.896**
V 1.4.0	V 1.5.0	21	0.0551784	21	4.2487	**25.2487**
V 1.5.0	V 1.7.0	6	0.0517208	6	1.08614	**7.08614**

Findings

Properties	General Purpose Commercial Software	Scientific Research Software
Characteristic path Length	2.8 - 3.2	2.2 - 2.7
Clustering co-efficient	0.2 - 0.45	0 - 0.2
Average Nodal Degree	7 - 20	3 – 8
Propagation Cost	5 - 17	3 - 7
Feedback Marks	Yes	No

- Iterative release analysis indicates
  - Clustering co-efficient decreased across the releases.
  - The most central function remained the same in all the releases.
  - The clustering co-efficient plays a vital role in the determination of release rework cost.

Software	Old Version	New Version	No. of New Elements	Clustering co-efficient	Rc_n
ADOL-C	V1.10.0	V2.1.0	116	0.106083	13.696
DyLP	V 1.3.0	V 1.4.0	65	0.258967	12.896

Software	Old Version	New Version	No. of New Elements	Clustering co-efficient	Rc_n
CppAD	V 110308	V 111103	33	0.0363174	3.5859
DyLP	V 1.4.0	V 1.5.0	21	0.258967	4.2487

Future Work

- There can a number of extension to this work
  - How to estimate the integration effort
  - Domain specific structural metrics

Thank You