A Next Generation Software Cost Model: a look under the hood

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Introduction

- Purpose of this talk is to describe a new NASA Software Cost Model that is under development
- It is built around a spectral clustering algorithm that can be used to estimate software size and effort that is effective for
  - small sample sizes
  - noisy data
  - and uses high level systems information

Background

- The *NASA Software CER Development Task is funded by the Cost Analysis Division to develop a software cost model that*
  - *Can be used in the early lifecycle*
  - *Can be used effectively by non-software specialists*
  - *Uses data from NASA in-house built and funded software "projects"*
    - *CADRe but also other Center level data sources*
  - *Supplement to current modeling and bottom up methods not a replacement*
  - *Can be documented as a paper model*
  - *Acceptable for use with both the cost and software communities*
- *Year 1 building a prototype model for robotic flight software*

Data Sources

- Where the data came from
  - CADRe (When it exists and is usable)
  - NASA 93 - Historical NASA data originally collected for ISS (1985-1990) and extended for NASA IV&V (2004-2007)
  - Contributed Center level data
  - NASA software inventory
  - Project websites and other sources for system level information if not available in CADRe

Data Items

- Total development effort in work months
- Delivered and equivalent logical lines
- COCOMO model inputs
  - Translated from CADRE which has SEER model inputs
- System parameters
  - Mission Type (deep-space, earth-moon, rover-lander, observatory)
  - Multiple element (probe, etc.)
  - Number of instruments (Simple, Medium&Complex)
  - Number of deployables (Simple, Medium&Complex)
  - Flight Computer Redundancy
  - Heritage

System Descriptor Details (Example)

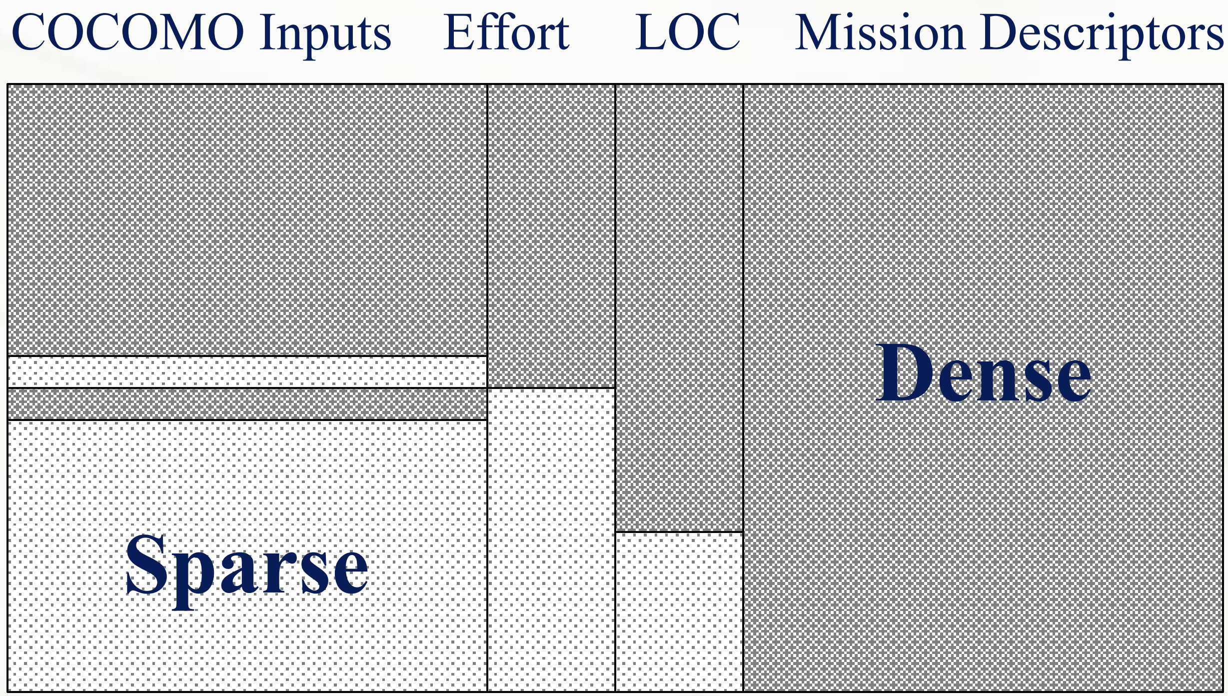
System Descriptors

Mission Type	Values	Description	Example
	Earth/Lunar Orbiter	Robotic spacecraft that orbit the earth or moon conducting science measurments. These spacecraft are very similar if not identical to the many commercial satellites used for communication as well as many military satelites. They often can have have high heritage and even use production line buses from industry.	Aqua
	Telecomm Sat	Earth orbiters that support very high bandwidth and designed for very long life.	TDRS
	Observatory	Observatories are space based telescopes that support space based astronomy across a wide set of frequencies. They can be earth orbiters or earth trailing at the various lagrange points created by the garvoty fields of the earth, sun and moon.	Hubble
	Deep Space	Any robotic sapcecarft that goes beyind the moons orbit. So this category includes any misison whose destination is a planet, planetoids, any planetary satelite, comet, asteroid or the sun. These misison can be orbiters or flybys or a mixture of both.	Deep Impact
	Static Lander	A robotic spacecraft that does its science in-situ or from the surface of a soplar system body. It does not move from its original location.	Phoenix
	Rover	A robotic spacecraft that does its science in-situ or from the surface of a solar system body and has the ability to move on the surface. To date all rovers have wheels but in the future they may crawl, walk or hop.	Mars Exploration Rover (MER)

- Complete list is in the backup slides

Data Yield

- 39 records with system descriptors mostly from GSFC and JPL
- 19 records have all data items
- 31 records have delivered LOC
- 21 records have effort



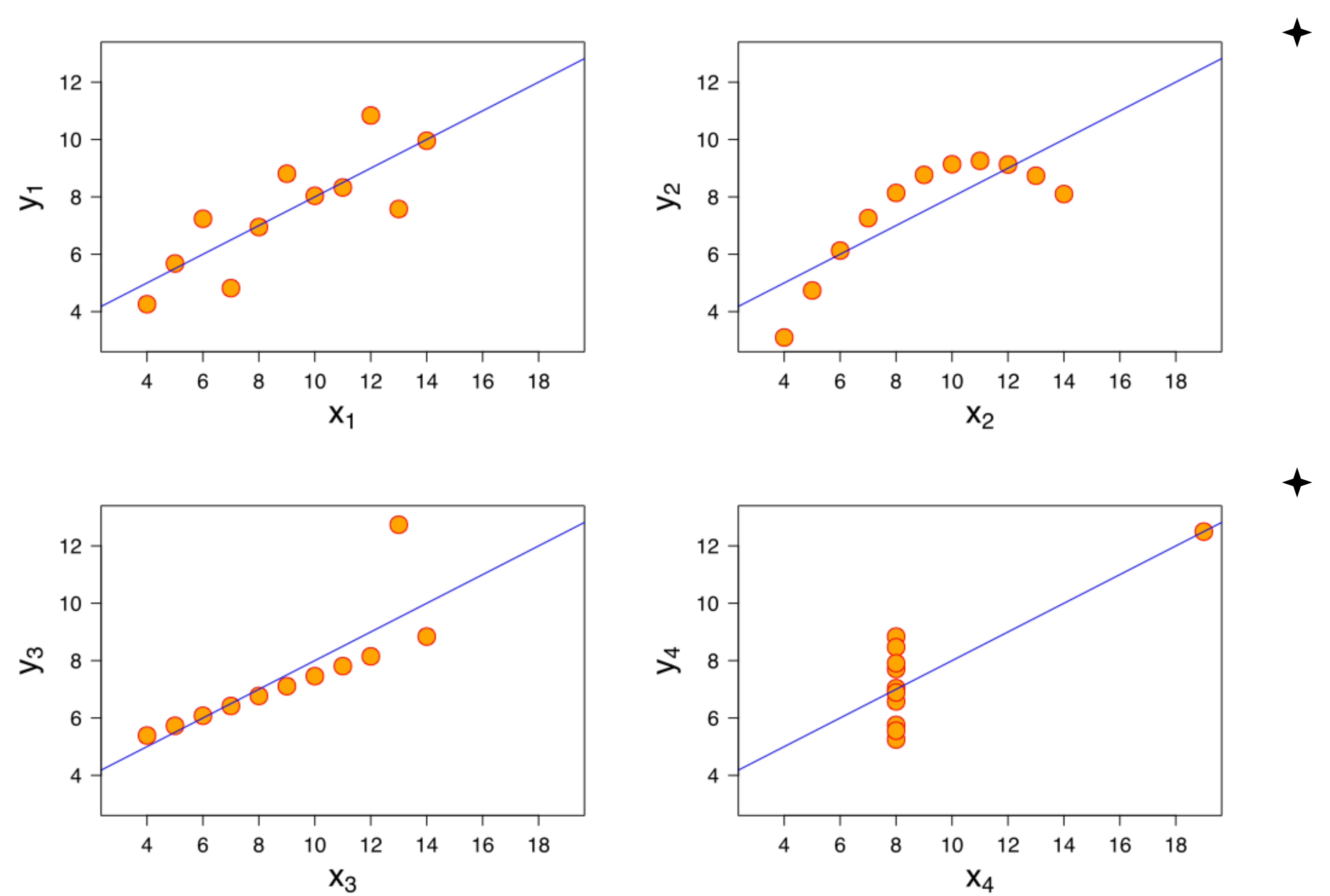
Why explore alternative modeling methods?

- For most of our history the cost community has relied upon regression type modeling methods
  - Regression method have the underlying assumption of
    - clean and complete data with large sample sizes
- Cost data suffers from sparseness, noise, and small sample sizes
- There are alternative methods that handle these conditions better then regression

Anscombe's Quartet

Models especially regression models built on small samples with noisy data can be very misleading

Anscombe's Quartet

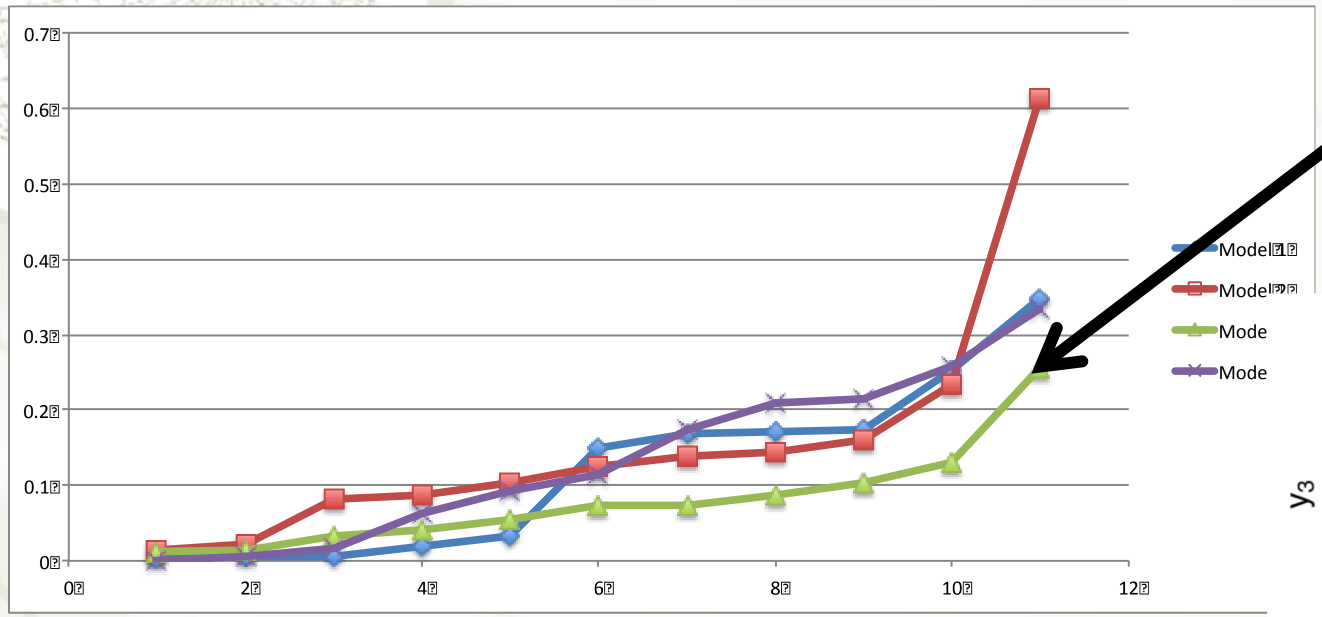


- All four of the displayed plots have virtually identical statistics
  - Means, Medians, Variances
  - Regression line, R^2, F and T tests
- But visual inspection clearly shows they are very different

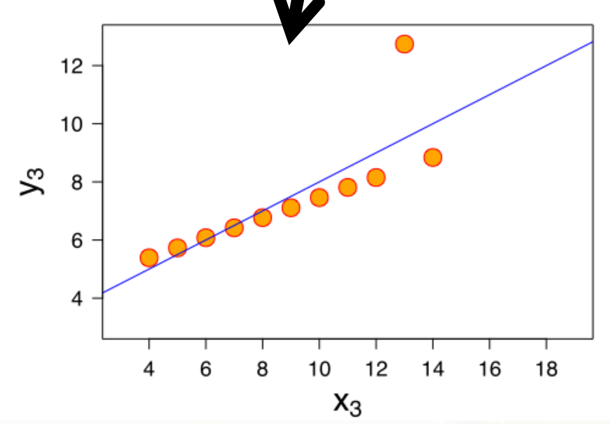
Reference: Anscombe, F. J. (1973). "Graphs in Statistical Analysis". *American Statistician* **27** (1): 17–21. JSTOR 2682899. Can also be found at http://en.wikipedia.org/wiki/Anscombe%27s_quartet

Anscombe's Quartet – Using MRE

- MRE can distinguish between the models



Model 3 fits its data the best



- Plotting the absolute values of the relative error it is easily seen that Model 3 fits its data best just as intuition would indicate
  - MRE = Magnitude of Relative Error, abs(Predicted – Actual)/Actual

Evolution of Methods

	1960s	1970s	1980s	1990s	2000s	Today
Is it possible to model cost?	PERT, LSR					
What parameters & functional form?		Parametric Models		Validated Robust Models Certification, Handbooks, Text Books		
How deal with uncertainty?				Probabilistic Estimation		
Can we do cost and schedule?		Cost and Schedule			JCL	
How do we deal with sparse and noisy data?					Bayesian Analogy/Clustering	

Draw line between 2 points

Multivariate Regression

Data Mining Methods

- Data mining techniques provided us with the rigorous tool set we needed to explore the many dimension of the problem we were addressing in a repeatable manner
  - Analyze standard and non-standard models
    - Is there a best functional form
  - Perform exhaustive searches over all parameters and records in order to guide data pruning
    - Rows (Stratification)
    - Columns (variable reduction)
  - Measure model performance by multiple measures
    - R^2, MRE, Pred, F-test, etc.
  - Is there a 'best' way to tune or calibrate a model

Effort Estimation with Data Mining Methods References

"Active Learning and Effort Estimation: Finding the Essential Content of Software Effort Estimation Data" by Ekrem Kocaguneli and Tim~Menzies and Jacky Keung and David Cok and Ray Madachy. IEEE Transactions on Software Engineering (pre-print) 2013 . .

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"On the Value of Ensemble Effort Estimation" by Kocaguneli, E. and Menzies, T. and Keung, J.. IEEE Transactions on Software Engineering 2011

"Exploring the Effort of General Software Project Activities with Data Mining" by Topi Haapio and Tim Menzies. International Journal of Software Engineering and Knowledge Engineering pages 725-753 2011

"Stable Rankings for Different Effort Models" by Tim Menzies and Omid Jalali and Jairus Hihn and Dan Baker and Karen Lum. Automated Software Engineering December 2010 . Available from http://menzies.us/pdf/10stable.pdf .

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"Explanation vs Performance in Data Mining: A Case Study with Predicting Runaway Projects" by Tim Menzies and O. Mizuno and Y. Takagi and Y. Kikuno. Journal of Software Engineering and Applications pages 221-236 November 2009

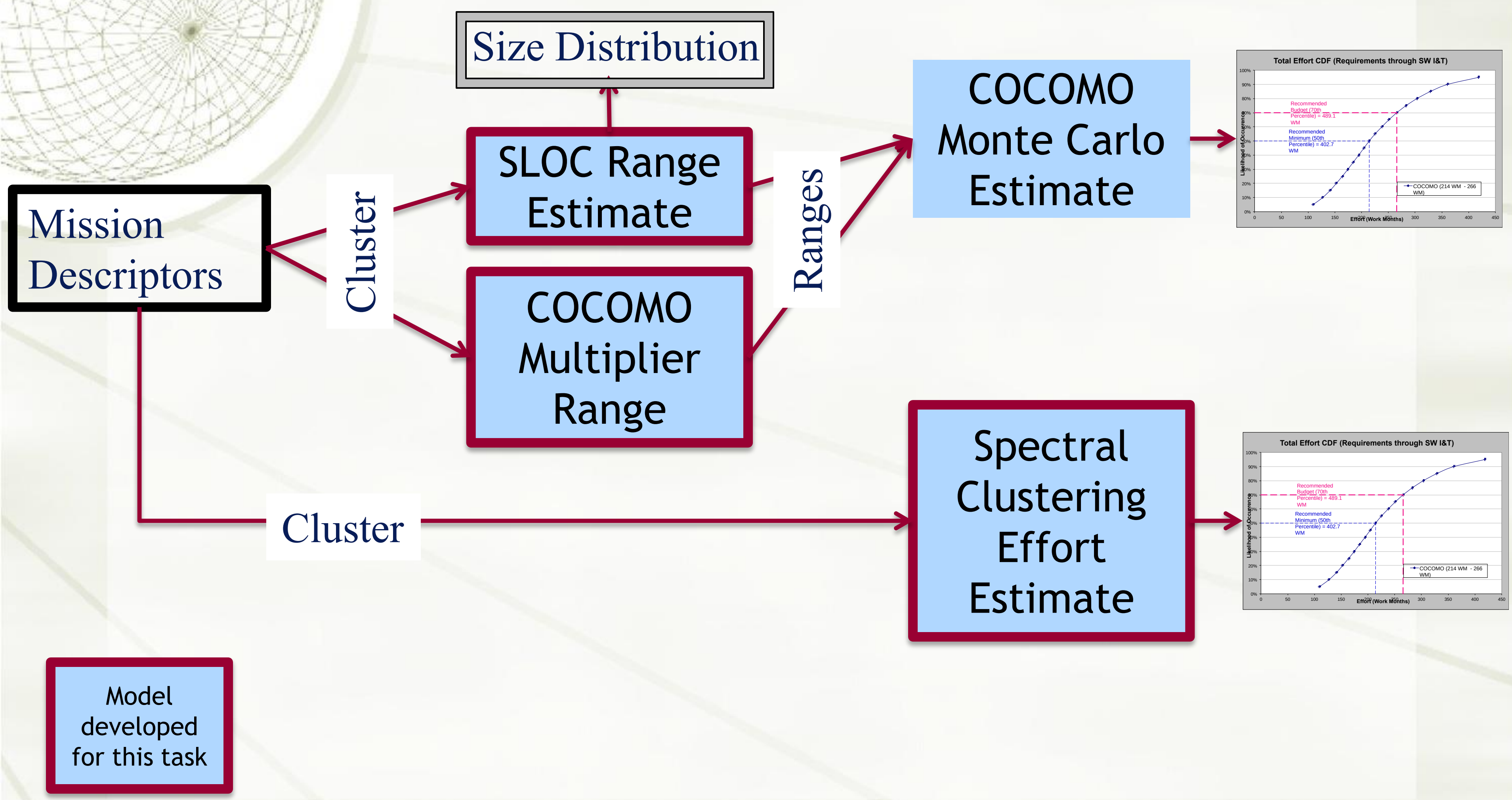
"Accurate Estimates Without Local Data?" by Tim Menzies and S. Williams and Oussama El-Rawas and D. Baker and B. Boehm and J. Hihn and K. Lum and R. Madachy. Software Process Improvement and Practice pages 213-225 July 2009 . Available from http://menzies.us/pdf/09nodata.pdf .

"Selecting Best Practices for Effort Estimation" by Menzies, Tim and Chen, Zhihao and Hihn, Jairus and Lum, Karen. IEEE Transactions on Software Engineering pages 883--895 doi = 10.1109/TSE.2006.114 issue = 11 2006

Spectral Clustering

- PCA finds eigenvectors in numerical data
- Spectral Clustering
  - Spectral Clustering is like PCA on steroids but uses an eigenvector approximation method
  - Recursively splits the data on synthesized dimension of greatest variance/spread
- Why use it
  - Can handle numerical and symbolic data
  - Can work on small, sparse and somewhat noisy data sets but also works well on large consistent data sets
  - Can use as estimator with partial information

Estimation Experiments

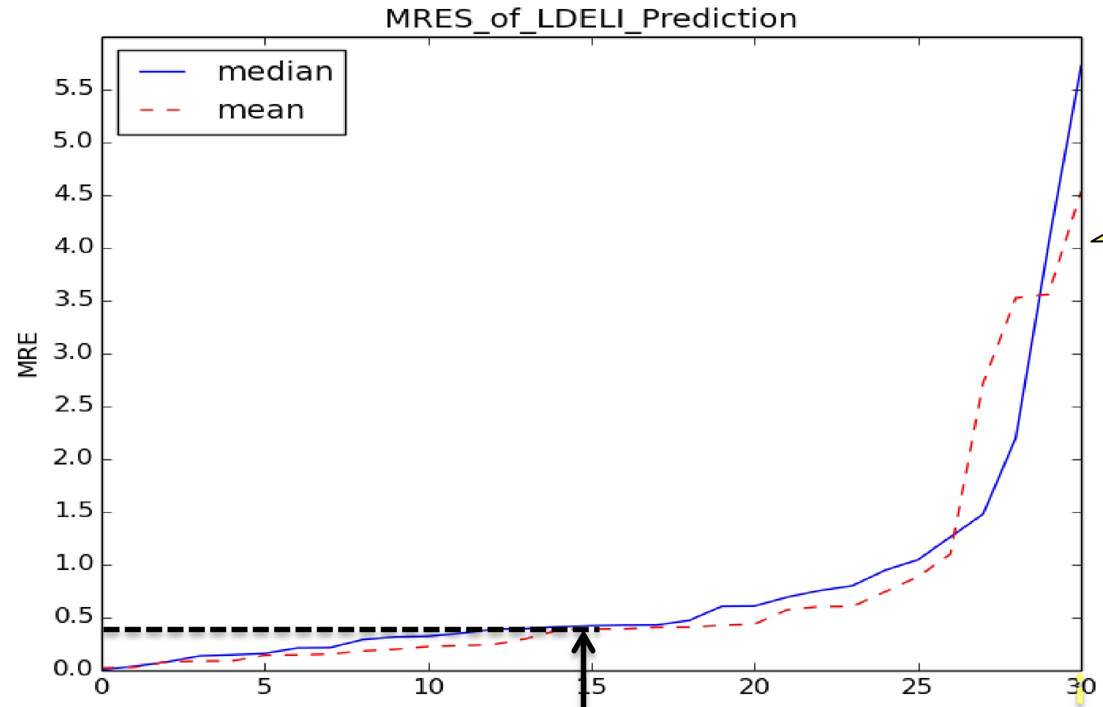


Side Note - Methodology Results

- Pure clustering
  - Median measures always win
    - Has implications for our commonly used regression based models which are regression to the mean
  - Interpolation beats centroid
    - Produces lower over all MRE
  - **Median distance between two clusters is best**
    - Produces lower over all MRE

SLOC Estimation

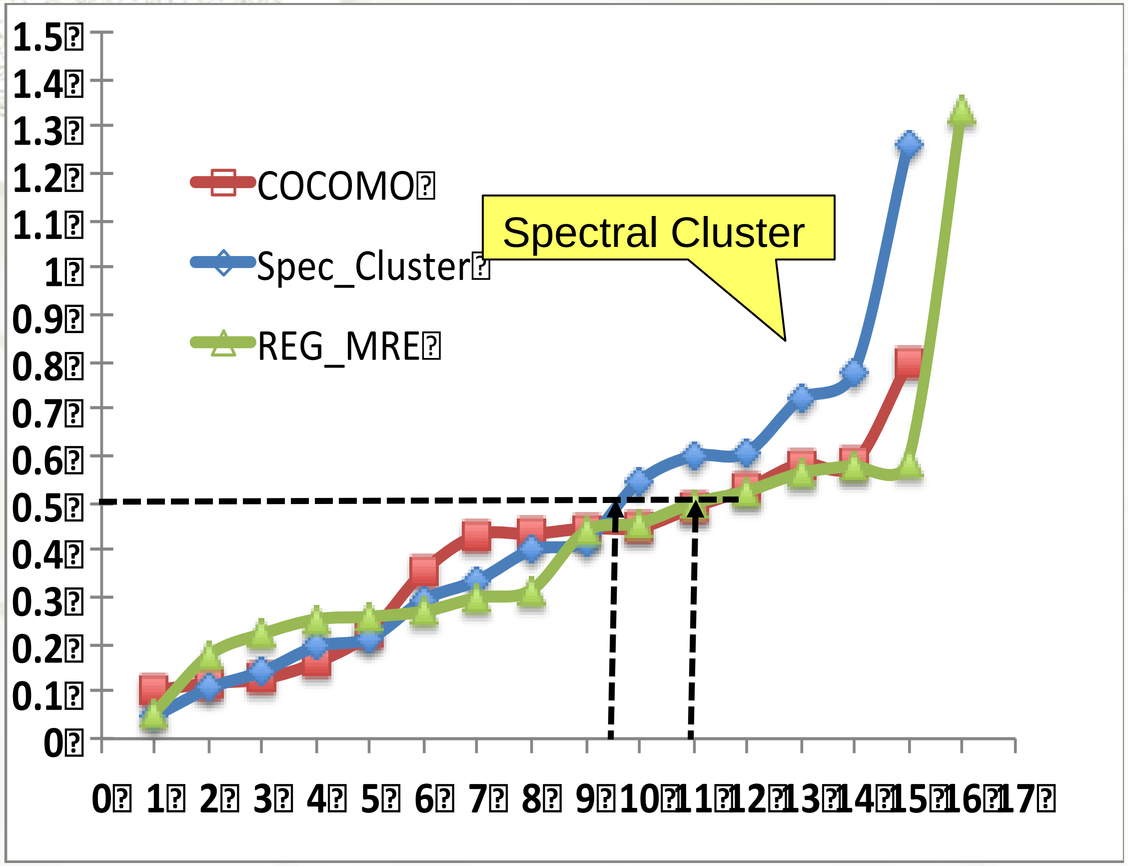
- Results so far are promising
  - Remember that software size growth of 50-100%+ is not uncommon



3 major outliers need to look into

Half the time, estimates within 40% of actual, using early life cycle data

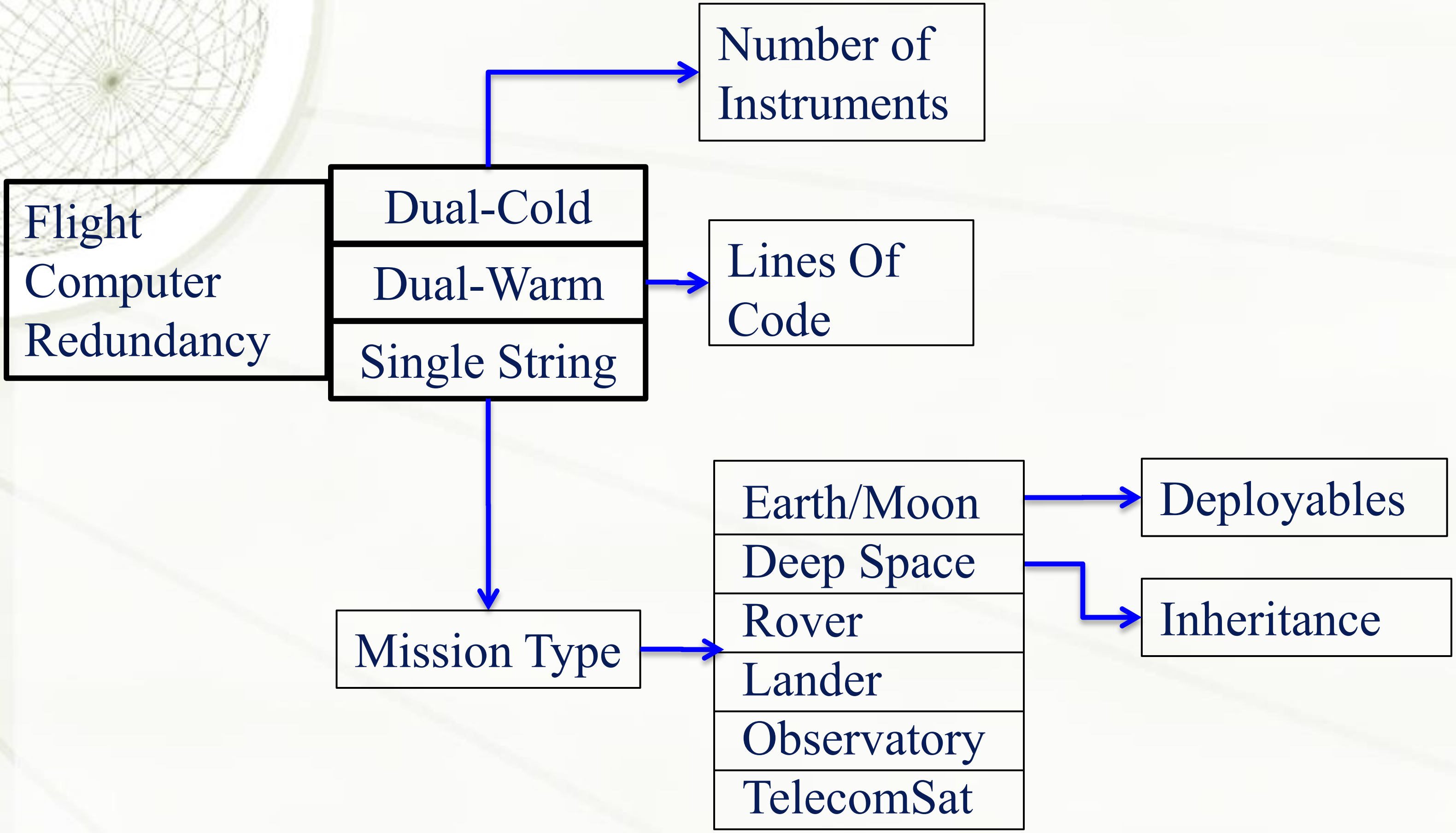
Clustering on Systems Parameters does almost as well as COCOMO or a Regression!



- Clustering using just high level system descriptors/variables estimates almost as good as running the COCOMO model or a simple regression
  - LSR - Effort/EM = aS^b
  - Results biased
- There is no inherent reason to assume with similar inputs that other models would perform any better

67-73% of estimates within +/-50% of actual, using early life cycle data

Cluster Discriminators



NASA SW Cluster Estimation Prototype
Example Clusters

COCOMO EM

Enter Data

System Descriptors

Rovers

_id	$StartYear	$prec	$flex	$resl	$team	$pmat	$rely	$cplx	$data	$ruse	$time	$stor	$pvol	$acap	$pcap	$pcon	$apex	$plex	$ltex	$tool	$sced	$site	$docu	$LogicalDeliver…d	Language	MissionType	SecondaryEle…	Complexity	$NumSimpleInstruments	$NumMediumInstruments	$NumINstr	FlightComputerRedundancy	$NumSimpleDeployables	$NoMediumDeployables	$NoComplexDeployables	Inheritance	Effort
	1997																								C	DeepSpace	None	Medium	1	2	3		10	0	2	LowtoNone	
	2000	3	3	3	3	3	4	5	3	2	3	3	4	4	4	5	4	4	4	2	1	5	3	324	C	Rover	EDL	Medium	0	5	5	DualString-Warmbackup	10	0	1	LowtoNone	1735.4
	1993	2	3	3	4	3	3	4	3	2	4	4	2	5	5	3	5	1	5	3	3	6	3	113.19	C	Rover	EDL	Simple	3	0	3	SingleString	10	0	1	LowtoNone	1080
	2007	3	2	4	3	3	4	4	3	4	3	3	4	3	4	4	4	3	3	3	3	5	3	597	C	Rover	EDL	Complex	0	10	10	DualString-Warmbackup	0	1	1	LowtoNone	1705
	2000	*3*	*3*	*4*	*4*	*3*	*4*	*4*	*3*	*3*	*4*	*4*	*3*	*4*	*5*	*4*	*5*	*2*	*4*	*3*	*3*	*6*	*3*	*355.1*	*C*	*Rover*	*EDL*	*Medium*	*2*	*5*	*7*	*DualString-Warmbackup*	*5*	*1*	*1*	*LowtoNone*	*1392.5*
	1998	4	3	3	4	4	4	4	3	2	3	3	2	3	3	3	5	3	4	2	3	6	3	50	C	DeepSpace	SampleReturn	Simple	2	1	3	DualString-Coldbackup	5	0	0	Veryhigh	637
	2002	3	2	3	3	3	4	5	3	3	3	3	5	4	4	3	4	3	3	3	2	6	3	224	C/C++/Assembly	DeepSpace	None	Complex	0	7	7	DualString-Coldbackup	1	0	0	Medium	691
	2005	3	2	2	3	4	4	4	3	2	3	3	3	?	?	?	?	?	?	?	3	5	3	108	C	Observatory	None	Simple	3	1	4	DualString-Coldbackup	1	0	0	Medium	446
	1995	4	3	3	4	4	4	4	3	2	3	3	2	3	3	3	5	3	4	2	3	6	3	50	C	DeepSpace	SampleReturn	Medium	2	0	2	DualString-Coldbackup	3	0	0	Veryhigh	546
	1997	4	3	3	3	4	4	4	3	2	3	3	2	3	3	3	5	3	4	2	3	5	3	60.5	C/Jovial	DeepSpace	None	Medium	2	1	3	DualString-Coldbackup	5	0	0	Veryhigh	336
	2009	4	2	3	3	4	4	3	3	2	3	3	2	4	3	3	5	4	4	2	3	5	3	170	C	DeepSpace	None	Medium	?	8	8	DualString-Coldbackup	0	1	0	Medium	552
	1997	*4*	*3*	*3*	*3*	*4*	*4*	*4*	*3*	*2*	*3*	*3*	*2*	*3*	*3*	*3*	*5*	*3*	*4*	*2*	*3*	*5*	[illegible]	*60.5*	*C*	*DeepSpace*	*None*	*Medium*	*2*	*1*	*3*	*DualString-Coldbackup*	*3*	*0*	*0*	*Veryhigh*	*546*
	1995	3	3	3	3	3	3	4	3	2	3	3	3	3	3	3	4	3	4	2	[illegible]	4	3	184	C	DeepSpace	None	Medium	2	0	2	SingleString	2	0	0	Medium	1042.8
	1998	3	3	3	2	3	4	5	3	2	3	3	3	3	3	3	4	3	4	[illegible]	[illegible]	5	3	253	C	Observatory	None	Medium	3	0	3	DualString-Coldbackup	0	2	0	Medium	2519
	2005	3	2	2	3	4	4	3	3	2	3	3	?	?	?	?	?	?	[illegible]	[illegible]	3	5	3	135	C	Earth/LunarOrbiter	None	Simple	1	0	1	SingleString	1	0	0	High	492
	2007	4	2	2	3	3	4	3	3	4	5	4	3	4	3	3	3	[illegible]	[illegible]	[illegible]	3	3	3	104.6	C	DeepSpace	None	Medium	6	3	9	DualString-Coldbackup	1	0	0	High	320
	2007	3	2	2	3	3	4	3	3	3	3	3	2	4	3	3	[illegible]	[illegible]	[illegible]	3	3	3	3	173.4	C	Earth/LunarOrbiter	None	Simple	4	0	4	SingleString	1	0	0	High	329
	2010	4	2	4	3	4	4	3	2	3	3	3	4	2	2	[illegible]	[illegible]	[illegible]	5	3	3	5	3	155	C	Earth/LunarOrbiter	None	Simple	2	1	3	SingleString	1	1	1	Medium	789
	2006	*3*	*2*	*3*	*3*	*3*	*4*	*3*	*3*	*3*	*3*	*3*	*3*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	*4*	*3*	*3*	*5*	*3*	*164.2*	*C*	*Earth/LunarOrbiter*	*None*	*Medium*	*3*	*0*	*3*	*SingleString*	*1*	*0*	*0*	*Medium*	*640.5*

Deep Space

Earth/Moon

Conclusions and Next steps

- Initial results very promising:
  - Reasonably accurate LOC estimators for early lifecycle data
  - Effort estimators for early lifecycle data
- Barry Boehm at the USC Center for Systems and Software Engineering is working with us and applying these methods on the COCOMO II data set
- Next Steps under consideration
  - Expand and improve SC flight software data set and add Instrument flight software
  - Test with SEER-SEM
  - Further explore combinations of data sets and methods for constructing clusters
  - Engage NASA software and cost community on how to pilot and improve the models

Back Up Slides

System Descriptors -1

System Descriptors

Mission Type	Values	Description	Example
	Earth/Lunar Orbiter	Robotic spacecraft that orbit the earth or moon conducting science measurments. These spacecraft are very similar if not identical to the many commercial satellites used for communication as well as many military satelites. They often can have have high heritage and even use production line buses from industry.	Aqua
	Telecomm Sat	Earth orbiters that support very high bandwidth and designed for very long life.	TDRS
	Observatory	Observatories are space based telescopes that support space based astronomy across a wide set of frequencies. They can be earth orbiters or earth trailing at the various lagrange points created by the garvoty fields of the earth, sun and moon.	Hubble
	Deep Space	Any robotic sapcecarft that goes beyind the moons orbit. So this category includes any misison whose destination is a planet, planetoids, any planetary satelite, comet, asteroid or the sun. These misison can be orbiters or flybys or a mixture of both.	Deep Impact
	Static Lander	A robotic spacecraft that does its science in-situ or from the surface of a soplar system body. It does not move from its original location.	Phoenix
	Rover	A robotic spacecraft that does its science in-situ or from the surface of a solar system body and has the ability to move on the surface. To date all rovers have wheels but in the future they may crawl, walk or hop.	Mars Exploration Rover (MER)
Secondary Element	**Values**	**Description**	**Example**
	None	No secondary element	Mars Reconsance Obiter (MRO)
	Probe or Impactor	A simple impactor with little or no guidance and navigation capabilityand once released it simply transmits data from its instruments. A moderate-complexity impactor which may receive commands after separation, may have some internal guidance control, and several moderately complex instruments.	Cassini-Huygens was a simple probe. Deep Impact had a medium complexity probe.
	Entry Descent and La	EDL can be simple with a ballastic trajectory or complex with precision landing and hazard avoidance. All landers and Rovers will have an EDL element.	Mars Pathfinder is an example of a simple EDL. MSL is an example of a complex EDL
	Sample return	A simple sample return is a like a simple probe but returning to earth. A complex sample reurn would be a return from a planet surface and requires an ascent stage.	Stardust is an example of a simple sample return

System Descriptors -2

Over All Complexity	Values	Description	Example
	Simple, Medium, or C	These are basd on the mission type and secondary element so are derived from the descriptions above	N/A
Number of Instruments	**Values**	**Description**	**Example**
	Simple	Any science instrument for which the FSW need only pass through commands and receive and store telemetry.	Magneometer
	Medium	Any science instrument for which the FSW must provide control logic that is relatively simple and requires no or only loose real time control. E.g., MER instruments.	MER Instruments
	Complex	Any science instrument for which the FSW must provide control logic that is complicated or requires tight real-time control.	Telescope
Flight Computer Redundancy	**Values**	**Description**	**Example**
	Single String	Spacecraft has no redundancy in the flight computer	Most Earth Orbiters
	Dual String – Cold bac	Spacecraft has redundant flight computers. Backup is normally off, is powered up and boots when prime string goes down	Most Deep Space missions
	Dual String – Warm ba	Backup computer is powered on and monitoring state of prime computer, but does not need to maintain continuous operation (e.g., a sequence may be restarted, attitude control restarts with last known state, etc.)	MSL

System Descriptors -3

Number of Deployables	Values	Description	Example
	Simple	Simple deployable(s) which activate one time and remain in the deployed position for the duration of the mission.	Magnetometer boom
	Medium	Moderately complex deployables which require some sequencing of deployment events, or may require deployment and retraction.	Deployable Solar arrays
	Complex	Complex deployables with detailed deployment sequences, many deployments and retractions which may require additional control algorithms to compensate for changing system characteristics, or deployables which are critical to mission safety and/or success.	Parachute, bag inflation and retraction, rover standup, ramp extension, complex robotic arms).
Inheritance	**Values**	**Description**	**Example**
	Low to None	Software to be inherited has never flown in space. Significant new design and basically all new code.	Mar Pathfinder or MSL EDL software
	Medium	Basic design has been used before but significant portion is new design and a code is newly written.	MSL
	High	Software to be inherited has flown in space and performed satisfactorily. Inherited SW architecture but majority of code is newly developed.	Many Planetary orbiiters
	Very High	Software to be inherited was developed as a product line, has flown successfully in space at least once, has been successfully re-used in at least two missions, and has extensive documentation.	Many earth orbiters

Spectral Clustering

- Select measure of distance
- Pick point A at random (near middle works better)
- Find furthest point from A (B)
- Find Furthest point for B (C)
- Draw line B-C
- Project all points onto the line and find the median. This is first eigenvector.
- Split data set by median point
- Repeat on each subset