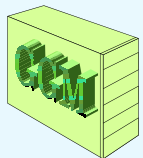




# PHYSICAL SYSTEM REPLICATION DIGITAL TWIN

March 2019

UNCLASSIFIED





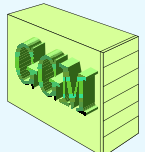
# *CAD for Prediction & Control Systems*



## **MEASURABLE APPLICATION GOALS:**

- Provide an order of magnitude reduction in the time & cost to develop models, simulations & systems;
- Provide 4 to 6 orders of magnitude improvement in simulation/system run-time speed
  - while cutting costs by orders of magnitude;
- Allow application experts to design, build, and test systems directly;
- Allow newcomers to a project to quickly learn and understand complex systems.

**Example Application: Use of Autonomous Vehicles with Network Facilities to achieve High A/J Margins**





## **TAKING PROPER MEASUREMENTS:**

**The principle Measure is the Speed Multiplier - SM:**

$$\mathbf{SM = Ts / Tp}$$

**where Ts is Time to run on a Single Processor - Fast  
and Tp is Time to run on a Parallel Processor**

**Depending upon the application**

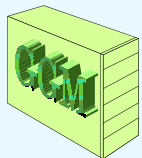
**– this may be difficult to measure**

**The critical Measure is Processor Utilization Efficiency:**

$$\mathbf{PUE = SM / Np}$$

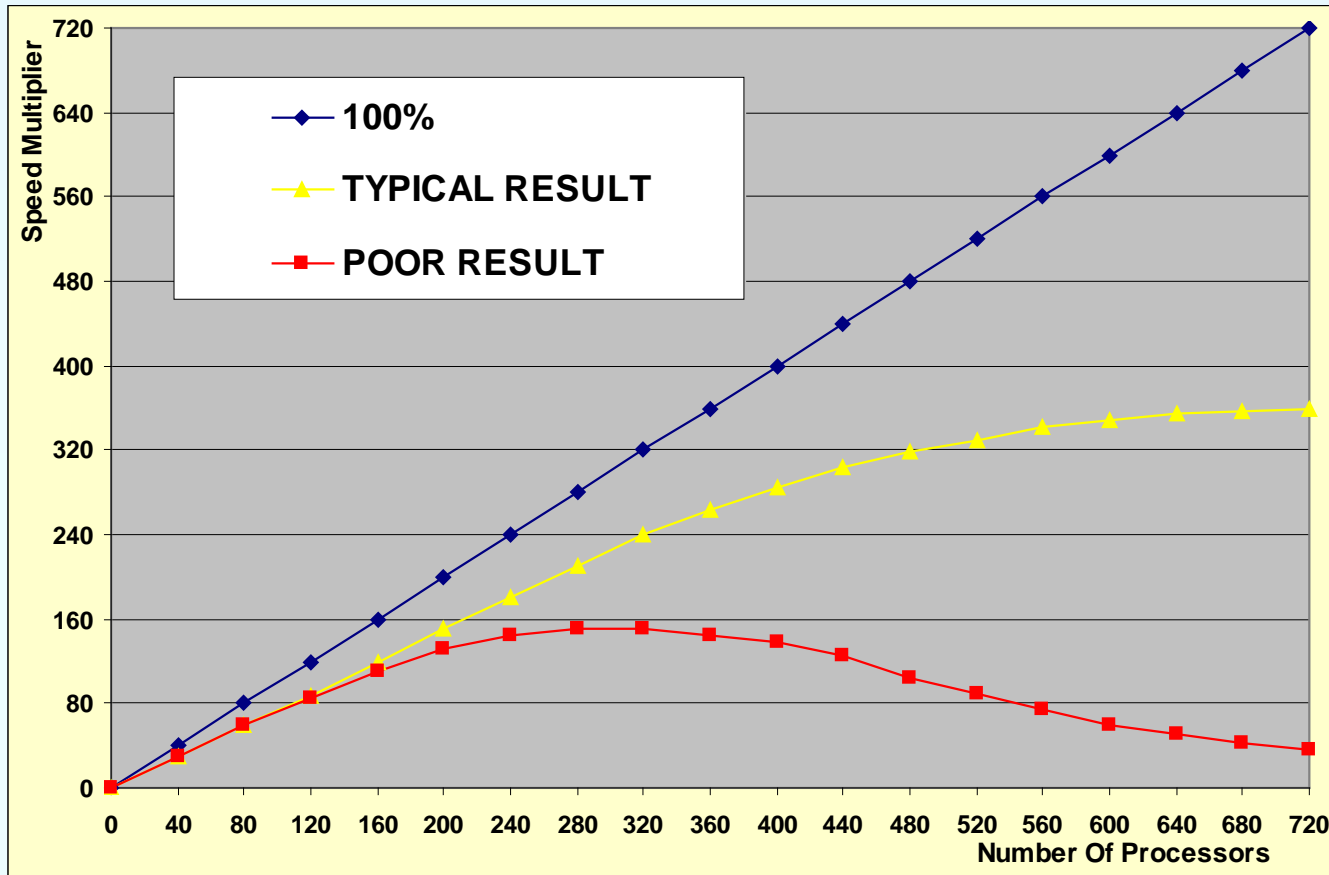
**where SM is the Speed Multiplier**

**and Np is the Number of Parallel Processors**



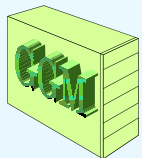


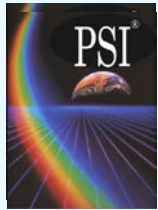
# CAD for Prediction & Control Systems



**The difference in speeds above is due to the Processor Utilization Efficiency (PUE)**

**VisiSoft PUEs can be above 95%**





***Von Neumann's***

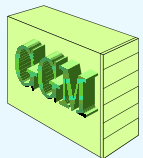
***Instruction Set Architecture***

***- the ISA for Single Processors***

***must be extended by VSI's***

***Application Space Architecture***

***- the ASA - for Parallel Processors***





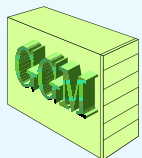
# *CAD for Prediction & Control Systems*



## **REPRESENTATIVE PARALLEL APPLICATIONS:**

- Adaptive Control of Large Groups of Autonomous Moving Platforms
- Human Body Organ simulation
- Human Brain – Artificial Intelligence modeling
- Global Climate prediction
- Currency Market prediction
- Chemical - Molecular structure simulation
- Scanning, sorting, and correlating massive databases (Big Data)
- Weather prediction in mountainous terrain
- Power distribution simulation
- Electro-magnetic wave simulation
- Global HF power transmission
- Global Military Planning - Multiple moving platform simulation

**THESE ARE NOT SERVER REQUIREMENTS!**

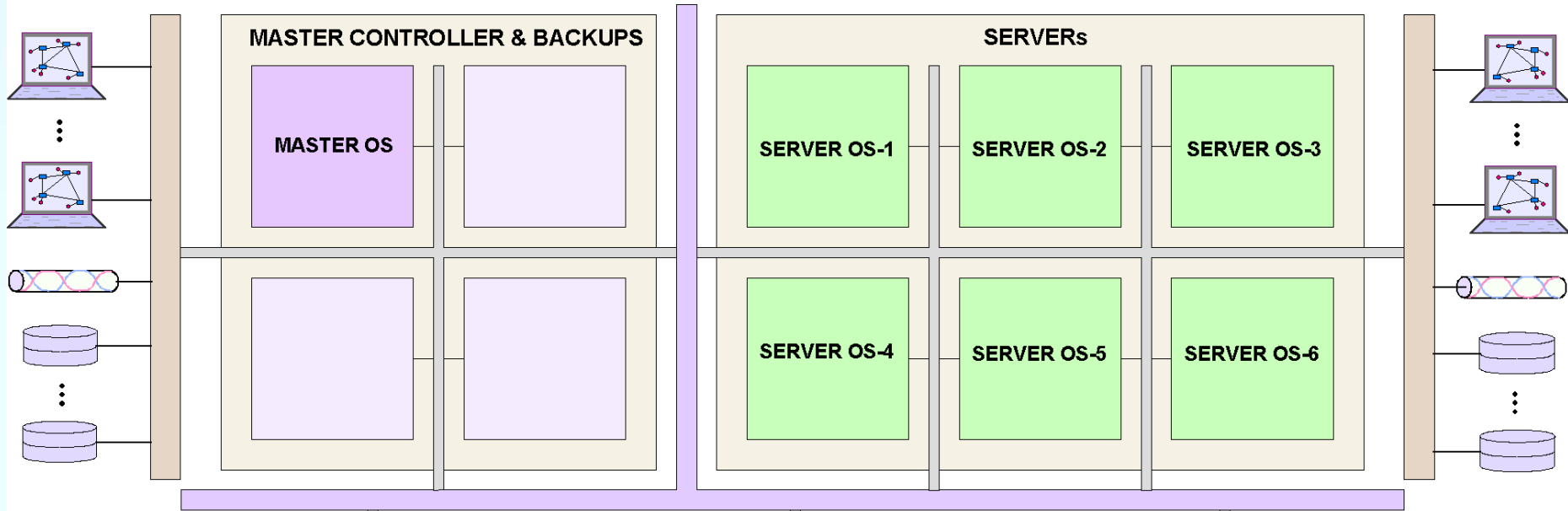




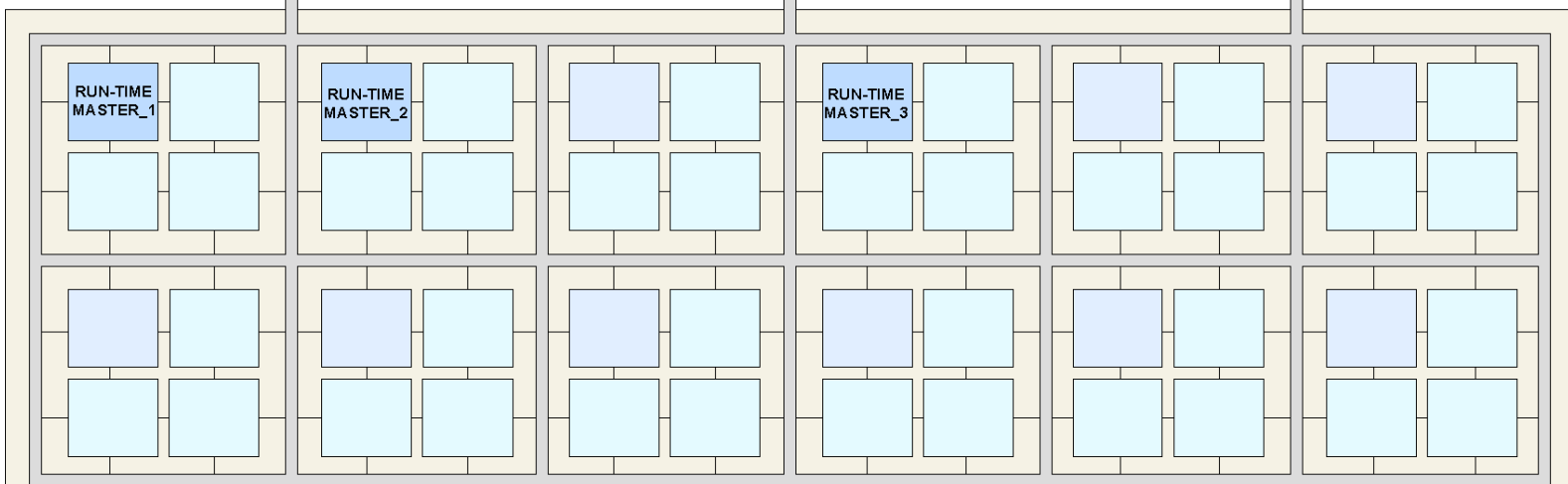
# And: - Servers Are Not Parallel Processors - A Multi-Tasking OS is Not a Parallel OS



## SERVER ARCHITECTURE



## PARALLEL PROCESSOR ARCHITECTURE





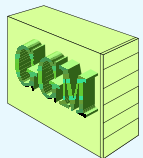
## **SOFTWARE IS AN EXTENSION OF MATHEMATICS:**

- **Must pick the “Best Spaces” to represent the problem;**
- **The Best Spaces provide independence (Kalman);**
- **They simplify the algorithms;**
- **Simple algorithms run much faster;**
- **Simple algorithms are much easier to understand;**
- **Newcomers to a project quickly learn the software**

**Also, What is a “Software Module” ?**

**And, What is “Software Architecture” ?**

**These terms are used throughout the literature – *undefined!***



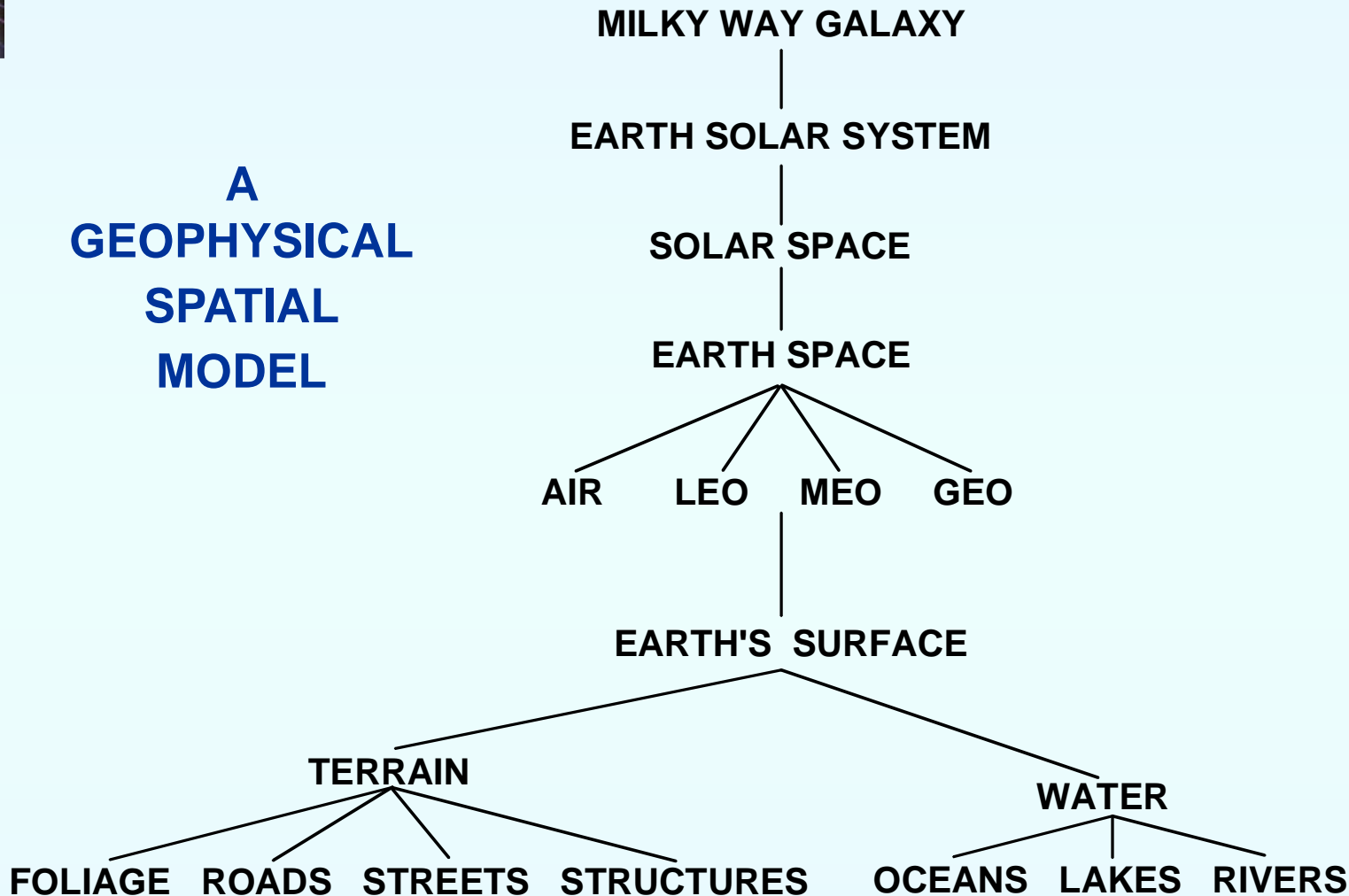




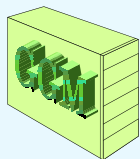
# EXAMPLE OF A MODEL SPACE HIERARCHY



**A  
GEOPHYSICAL  
SPATIAL  
MODEL**

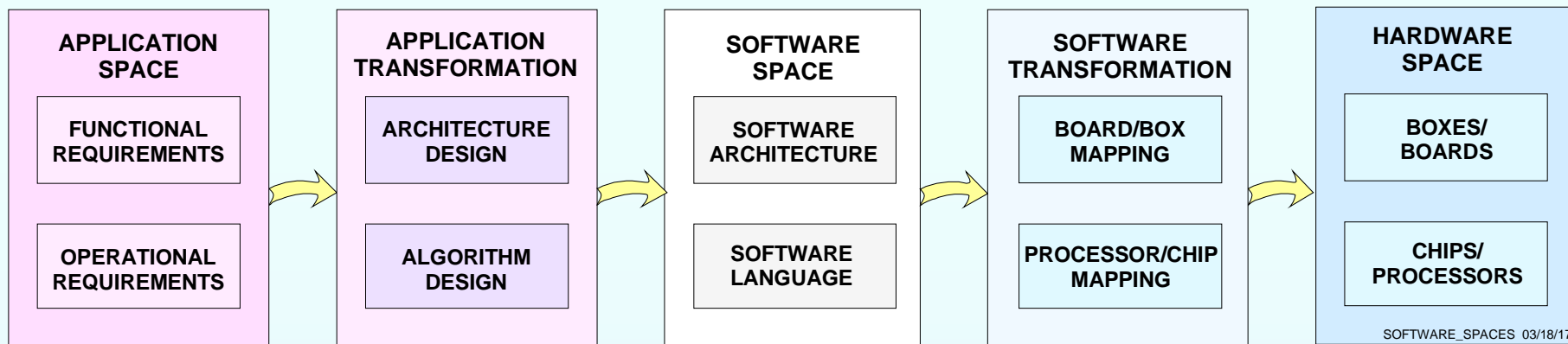


**SUCH MODELS SUPPORT HETEROGENEOUS HIERARCHIES  
WITH ACCURACIES DOWN TO 1.1 CM**

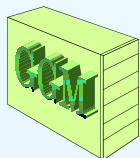




## Spaces for Translation of Application Requirements into Software Requirements & then into Hardware Requirements



## Defining the: Application Space Architecture (the ASA)





# CAD for Prediction & Control Systems



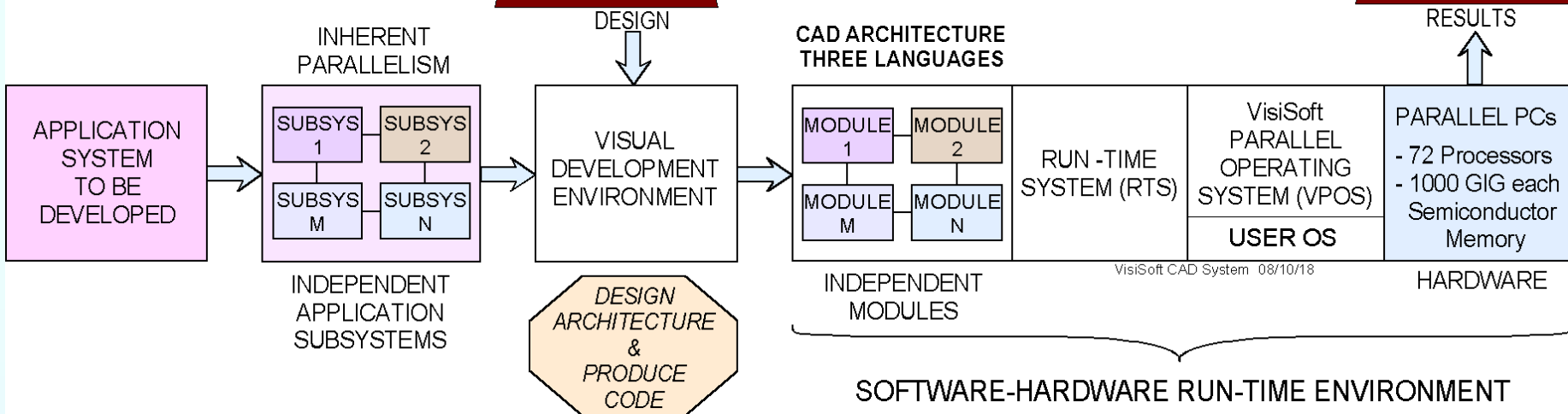
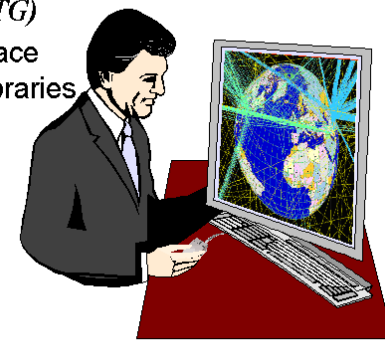
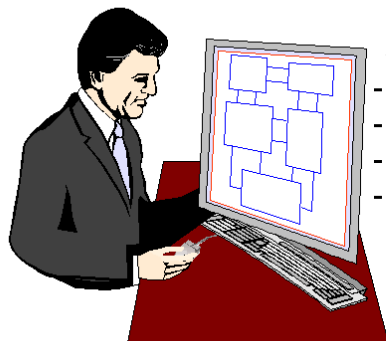
## APPLICATION EXPERTS USE

*Visual Software Environment (VSE)*

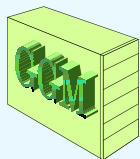
- CAD GUI
- Engineering Drawings
- Natural Language
- Large Libraries

*Run Time Graphics (RTG)*

- Graphical User Interface
- Large Geographic Libraries
- Interactive Facilities



# Visual Software Engineering Using A CAD System For Building Real-Time Control Systems





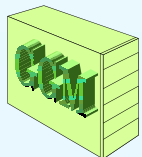
# CAD for Prediction & Control Systems



a RESOURCE  
-  
Contains  
Hierarchical  
Data Structures  
To  
Easily Map  
Complex Spaces

RESOURCE: TRANSCEIVER		INSTANCES: TRANSMITTER RECEIVER	
<b>GENERAL PARAMETERS</b>			
1	TRANSMITTER_POWER	REAL	INITIAL_VALUE 100
1	RECEIVER_THRESHOLD	REAL	INITIAL_VALUE 120
<b>RADIO</b>			
1	TRANSCEIVER	<b>STATUS</b>	TRANSMITTING RECEIVING IDLE OFF
1	LOCATION		
2	X_POSITION	REAL	
2	Y_POSITION	REAL	
2	ELEVATION	REAL	
1	ANTENNA_HEIGHT	REAL	
1	ANTENNA_GAIN	REAL	
<b>RECEIVER_CONNECTIVITY_VECTOR</b>			
1	POWER_AT_RECEIVER	REAL	
1	TOTAL_NOISE_POWER	REAL	
1	CONNECTIVITY_MATRIX		
2	PROPAGATION_LOSSES		
3	TERRAIN_LOSS	REAL	
3	FOLIAGE_LOSS	REAL	
3	TOTAL_LOSS	REAL	
2	SIGNAL_POWER	REAL	
2	SIGNAL_TO_NOISE_RATIO	REAL	
2	LINK_DELAY	REAL	
2	LINK	<b>STATUS</b>	GOOD FAIR POOR
<b>TRANSCEIVER_RULES</b>			
1	TRANSCEIVER_PROCESS	<b>RULES</b>	GOOD_RECEPTION CONFLICTING_RECEPTION CONFLICTING_BROADCAST

## A Space / Data Structure





# CAD for Prediction & Control Systems



```

PROCESS: RECEPTION
INSTANCES: TRANSMITTER
           RECEIVER

RESOURCES: TRANSCIEVER
           MESSAGE_FORMATS
           TRANSMITTER_OUTPUT

```

```

START_RECEPTION
  IF TRANSCIEVER IS IDLE
    EXECUTE GOOD_RECEPTION
  ELSE IF TRANSCIEVER IS RECEIVING
    EXECUTE CONFLICTING_RECEPTION
  ELSE IF TRANSCIEVER IS TRANSMITTING
    EXECUTE CONFLICTING_BROADCAST .

GOOD_RECEPTION
  IF SIGNAL_TO_NOISE_RATIO IS GREATER_THAN RECEIVER_THRESHOLD
    SET TRANSCIEVER TO RECEIVING
    ADD SIGNAL_POWER TO TOTAL_POWER_AT_RECEIVER .
    CALL DECODE_MESSAGE .

  IF MESSAGE_TYPE IS FORMAT_A
  AND SYNC_CODE IS VALID
  AND LAST_SYMBOL IS A_TERMINATOR
    EXECUTE SEND_ACKNOWLEDGEMENT .

CONFLICTING_RECEPTION
  IF POWER_AT_RECEIVER IS GREATER_THAN SIGNAL_POWER
    SCHEDULE ABORT_RECEIVE NOW .

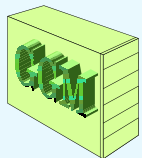
CONFLICTING_BROADCAST
  CANCEL END_RECEIVE NOW
  SCHEDULE START_RECEIVE IN EXPON(0.83) MILLISECONDS
  WITH PRIORITY 80

SEND_ACKNOWLEDGEMENT
  MOVE ACKNOWLEDGEMENT TO TRANSMIT_MESSAGE_BUFFER
  IF DESTINATION IS BROADCAST
    SEARCH LINK_CONNECTIVITY_VECTOR OVER RECEIVER
    EXECUTING TRANSMISSION
    WHEN LINK IS GOOD
  ELSE EXECUTE TRANSMISSION .

TRANSMISSION
  SCHEDULE LINK_RECEPTION
  IN LINK_DELAY MICROSECONDS
  USING TRANSMITTER, RECEIVER

```

a PROCESS  
-  
Contains  
Hierarchical  
Rule Structures  
That Support  
One-in One-out  
Independent  
Control Structures  
(Mills)

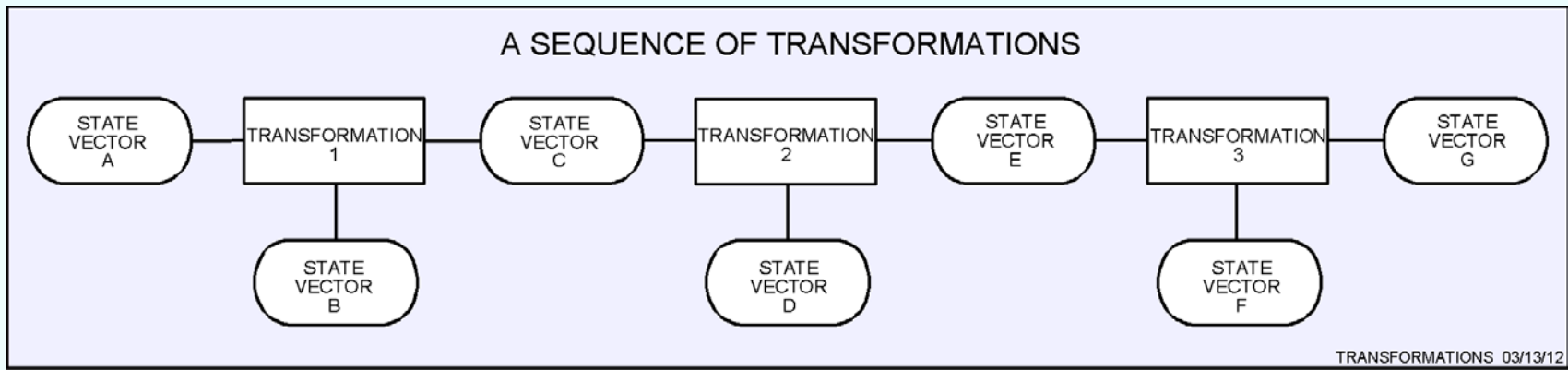


## A Transformation / Rule Structure

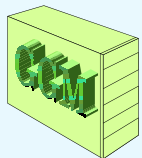
PREDICTION & CONTROL SYSTEMS ENGINEERS



## Spaces for Translation of Application Requirements into Software & Hardware



**Connecting Resources & Processes to Create a Sequence of Transformations**  
**- Mathematically Defining a Module**

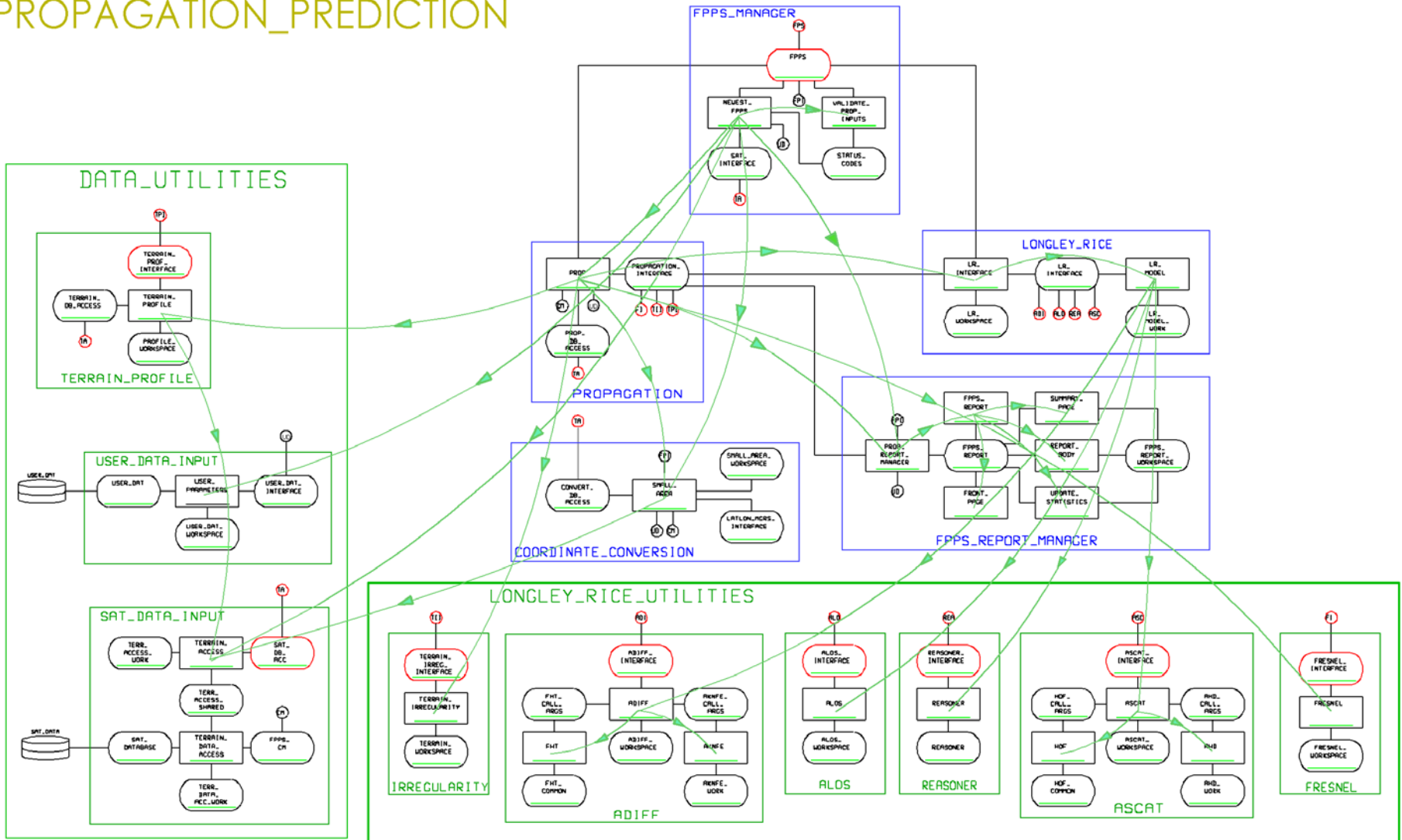




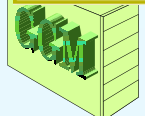
# CAD for Prediction & Control Systems



## PROPAGATION\_PREDICTION



FPPS 08/26/19



# An Architecture - a Hierarchy of Modules

PREDICTION & CONTROL SYSTEMS ENGINEERS





# CAD for Prediction & Control Systems

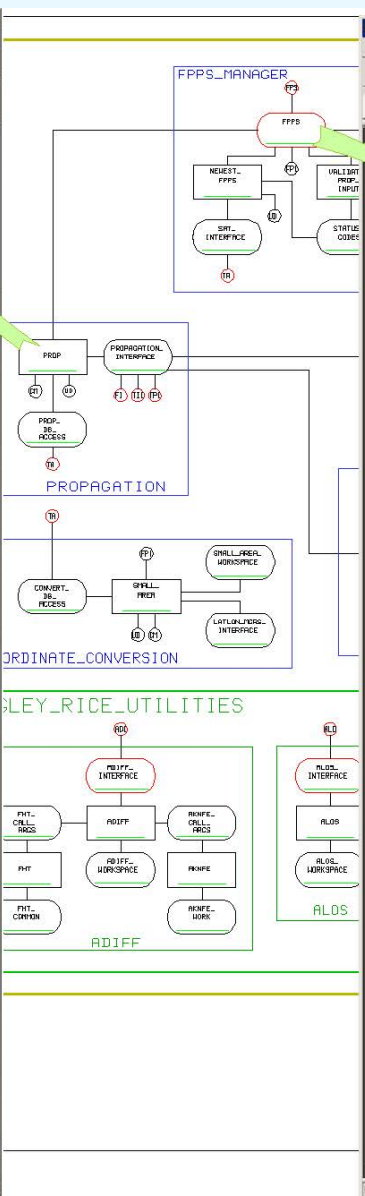


```

UltraEdit-32 - [C:\S\LIBS\FPPS_VERSIONS\FPPS\PROP_FOR_PICTURE.PRO]
PROP_FOR_PICTURE.PRO

1 PROPAGATION_MODEL
2 IF USER_DATA_STATUS IS NOT INITIALIZED
3 MOVE USER_DAT_INTERFACE TO USER_DATA
4 EXECUTE FOLIAGE_HEIGHT_INPUT .
5
6 IF SYSTEM_ACTION IS PROPAGATION_CALC
7 OR SYSTEM_ACTION IS EQUAL TO LOS
8 EXECUTE COMPUTE_SECTION
9 ELSE
10 IF SYSTEM_ACTION IS RECOMPUTE
11 EXECUTE RECOMPUTE_SECTION .
12
13 IF ERROR_CODE IS NOT DETECTED
14 AND REPORT_SELECTION IS OPEN
15 CALL PROP_REPORT_MANAGER .
16
17 FOLIAGE_HEIGHT_INPUT
18 IF PROCESS_FOLIAGE_FLAG IS SET
19 MOVE USER_DAT_INTERFACE AVER_BUILDING_HEIGHT
20 TO FOLIAGE_HEIGHT .
21
22 COMPUTE_SECTION
23 CALL VALIDATE_PROP_INPUTS
24 IF ERROR_CODE IS DETECTED
25 EXIT THIS RULE .
26
27 EXECUTE COMPUTE_COORDINATES
28 EXECUTE COMPUTE_ANTENNA_HEIGHTS
29 EXECUTE CALCULATE_FREESPACE_LOSS
30 EXECUTE BUILD_TERRAIN_PROFILE
31
32 IF PATH_PROFILE_ONLY_FLAG IS SET
33 EXIT THIS RULE.
34
35 CALL TERRAIN_IRREGULARITY
36 IF PROCESS_FOLIAGE_FLAG IS SET
37 EXECUTE INVOKE_FOLIAGE_MODEL .
38
39 EXECUTE CALC EFF ANT HEIGHTS
40 EXECUTE INVOKE_TERRAIN_MODEL
41 EXCESS_PATH_LOSS = EXCESS_PATH_LOSS + FOLIAGE_LOSS
42
43 RECOMPUTE_SECTION
44 EXECUTE CALCULATE_FREESPACE_LOSS
45 IF PROCESS_FOLIAGE_FLAG IS SET
46 EXECUTE INVOKE_FOLIAGE_MODEL .
47
48 EXECUTE INVOKE_TERRAIN_MODEL
49
50 COMPUTE_COORDINATES
51 START_X = (XMTR_REL_X + DBASE_SCALE) / DBASE_SCALE
52 START_Y = (XMTR_REL_Y + DBASE_SCALE) / DBASE_SCALE
53 END_X = (RCVR_REL_X + DBASE_SCALE) / DBASE_SCALE
54 END_Y = (RCVR_REL_Y + DBASE_SCALE) / DBASE_SCALE

```

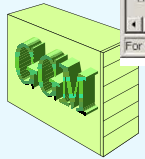


```

UltraEdit-32 - [C:\S\LIBS\FPPS_VERSIONS\FPPS\FPPS.RES]
FPPS.RES

1 FPPS INPUT DATA
2 SYSTEM_PARAMETERS
3
4 2 SYSTEM ACTION
5 ALIAS VALID_SYSTEM_ACTION VALUE 'C','R','X','Y'
6 ALIAS INITIALIZATION VALUE 'I'
7 ALIAS TRANSFORMATION VALUE 'X','Y'
8 ALIAS PROPAGATION_CALC VALUE 'C','R','P'
9 ALIAS REPORT VALUE 'I'
10
11 2 ALGORITHM_CHOICE
12 ALIAS VALID_ALG_CHOICE VALUE 6,7,8,9
13 ALIAS GET_ELEVATION VALUE 1
14 2 PATH_PROFILE_ONLY_FLAG
15 ALIAS SET VALUE 'Y'
16 2 LOS_ONLY_FLAG
17 ALIAS SET VALUE 'Y'
18 2 PROCESS_FOLIAGE_FLAG
19 ALIAS SET VALUE 'Y'
20 2 REPORT_SELECTION
21 ALIAS VALID_RPT_SELECTION VALUE 'E','S','M'
22 ALIAS OPEN VALUE 'E','S'
23 ALIAS FULL VALUE 'E'
24 ALIAS SUMMARY VALUE 'S'
25 2 PAD CHAR 04
26
27 1 COORDINATE_SYSTEM
28 ALIAS VALID_COORD_SELECTION VALUE 'I','M','L'
29 ALIAS LATION VALUE 'L'
30 ALIAS MGRS VALUE 'M'
31 ALIAS INTERNAL VALUE 'I'
32
33 1 XMTR_POSITION
34 2 XMTR_REL_POSITION
35 3 XMTR_REL_X REAL
36 3 XMTR_REL_Y REAL
37 3 XMTR_REL_Z REAL
38 2 XMTR_MGR_POSITION CHAR 15
39 2 XMTR_GEO_POSITION
40 3 XMTR_LAT REAL
41 3 XMTR_LON REAL
42 2 XMTR_ANTENNA_HEIGHT REAL
43 2 XMTR_ANTENNA_REFERENCE CHAR 1
44 ALIAS VALID_REFERENCE VALUE 'S','G'
45 ALIAS SEA VALUE 'S'
46 ALIAS GROUND VALUE 'G'
47
48 1 RCVR_POSITION
49 2 RCVR_REL_POSITION
50 3 RCVR_REL_X REAL
51 3 RCVR_REL_Y REAL
52 3 RCVR_REL_Z REAL
53 2 RCVR_MGR_POSITION CHAR 15
54 2 RCVR_GEO_POSITION
55 3 RCVR_LAT REAL
56 3 RCVR_LON REAL
57 2 RCVR_ANTENNA_HEIGHT REAL
58 2 RCVR_ANTENNA_REFERENCE CHAR 1

```



## Double Click To Edit The Code

PREDICTION & CONTROL SYSTEMS ENGINEERS



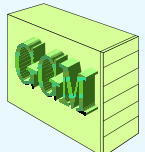
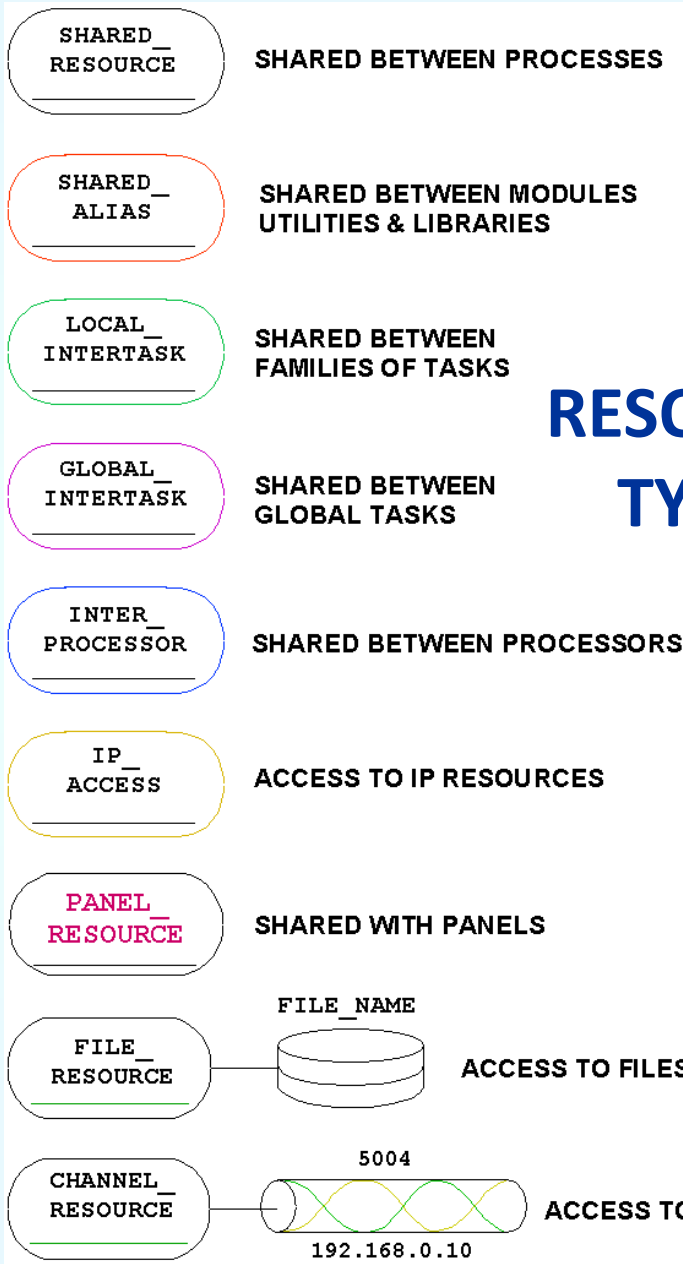


# CAD for Prediction & Control Systems



**RESOURCE TYPES ARE CRITICAL TO SHARING DATA & MAPPING MODULES ONTO PARALLEL PROCESSORS**

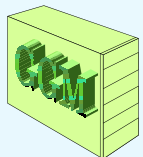
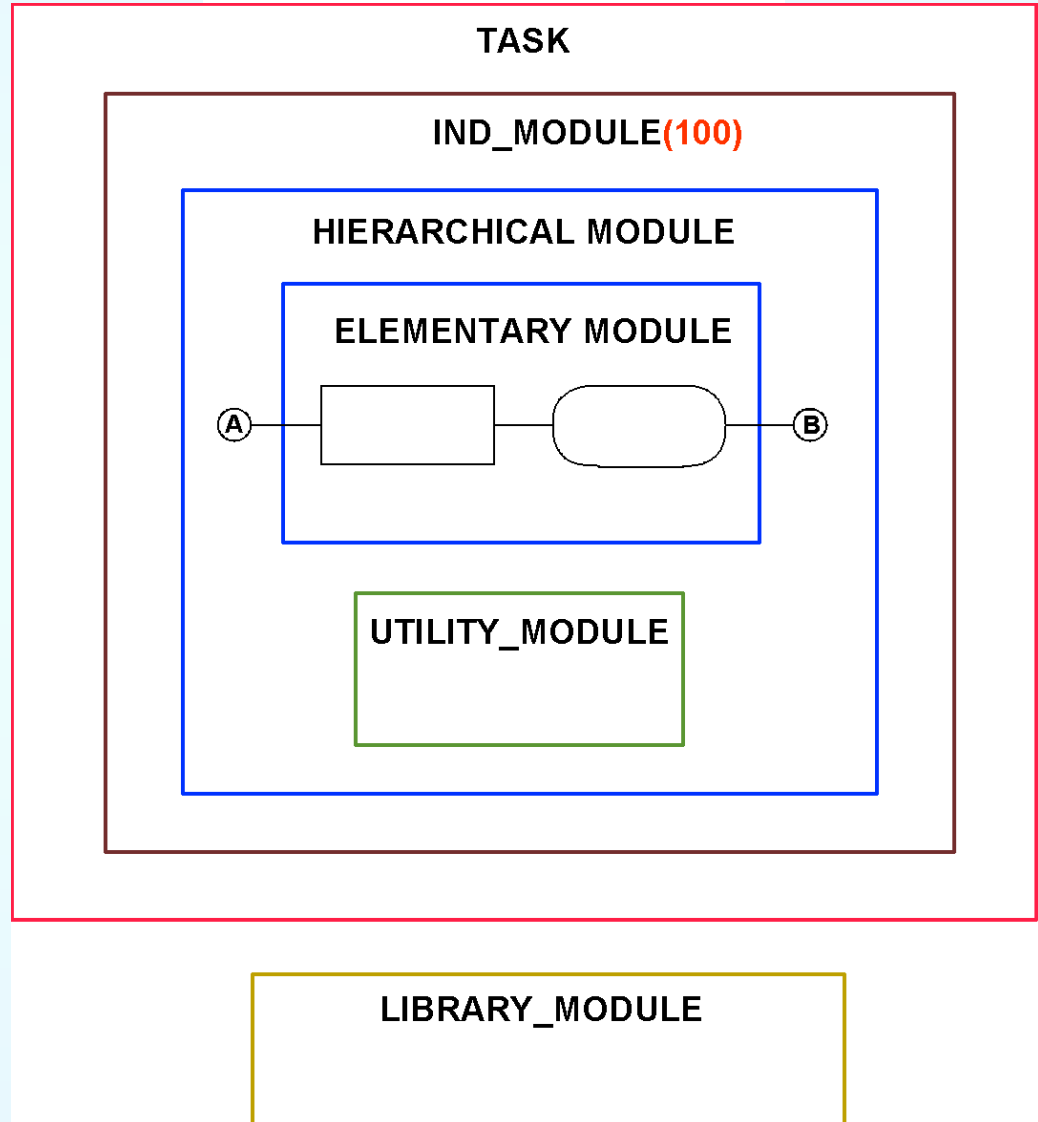
**RESOURCE TYPES**



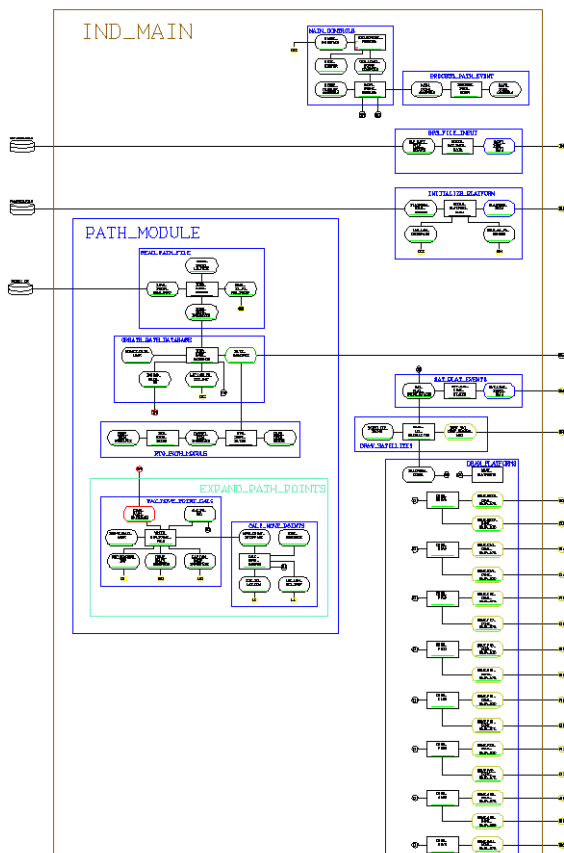


## MODULE TYPES

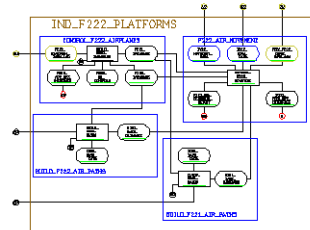
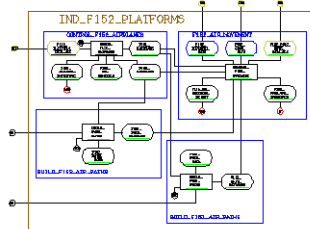
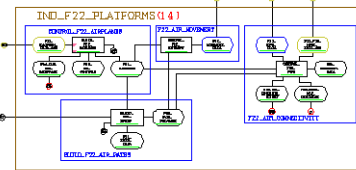
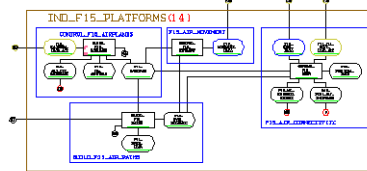
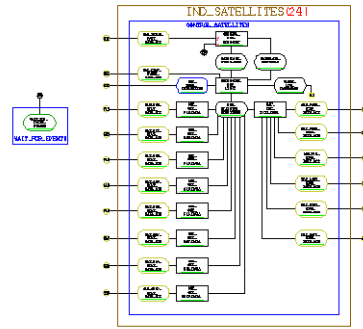
**MODULE TYPES ARE CRITICAL TO INDEPENDENCE & ARCHITECTURAL MAPPING OF MODULES ONTO PARALLEL PROCESSORS**



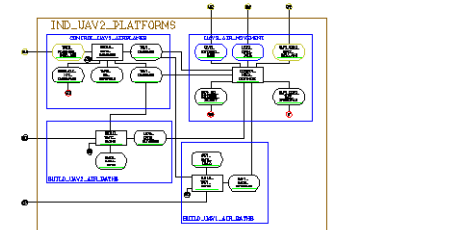
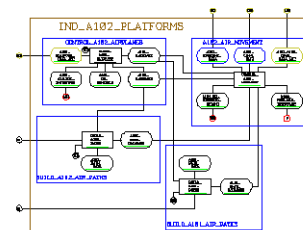
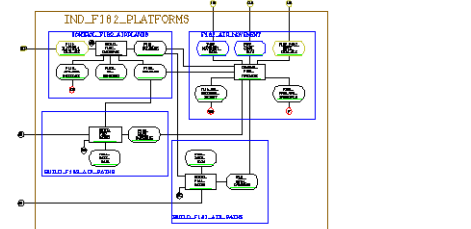
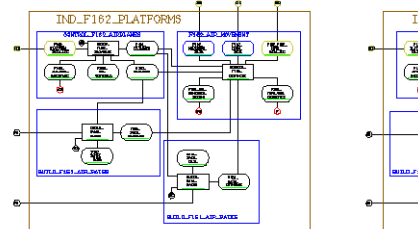
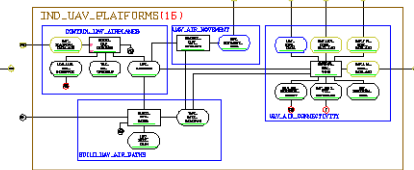
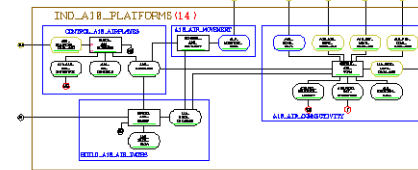
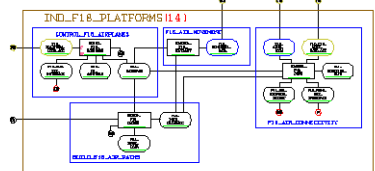
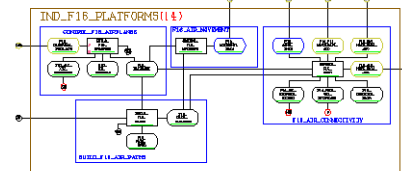
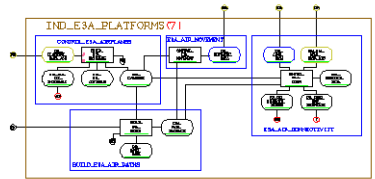
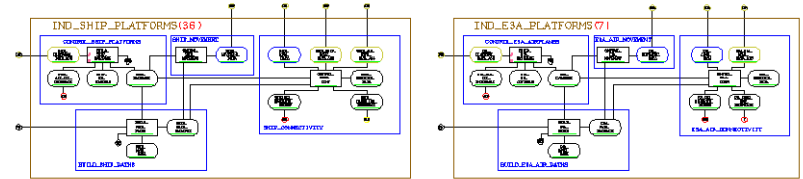
GLOBAL\_PLANNER

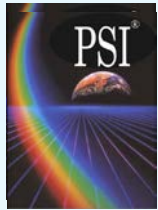


**GLOBAL\_PLANNER**  
**153 PLATFORMS**  
**16 Processor PC**  
**12 hour scenario**  
**2.31 seconds**



## A Parallel Processor Simulation Architecture

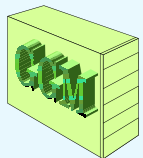




# *CAD for Prediction & Control Systems*



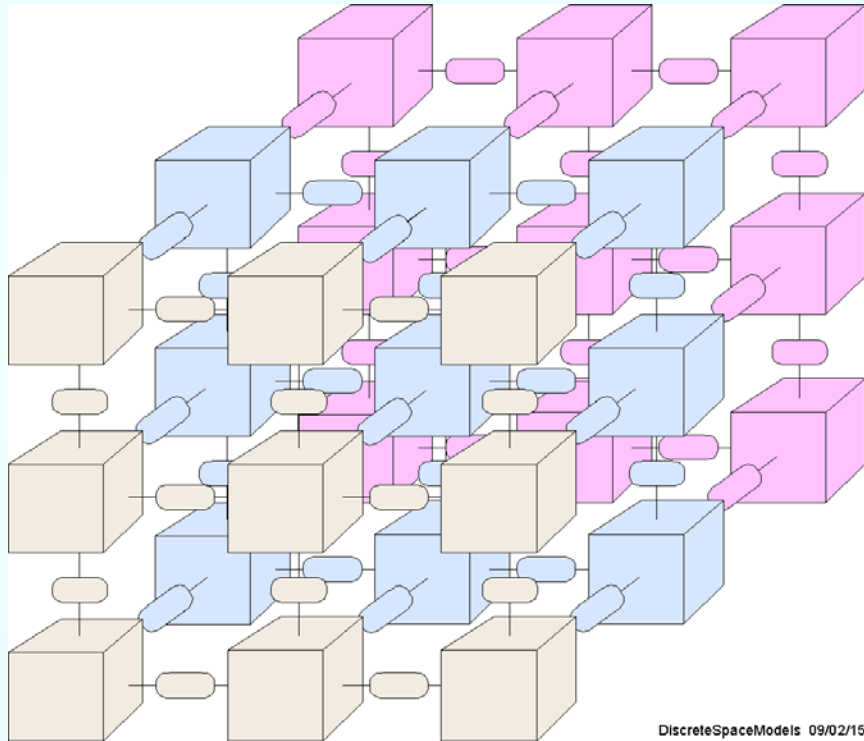
## ***BACKUP SLIDES***





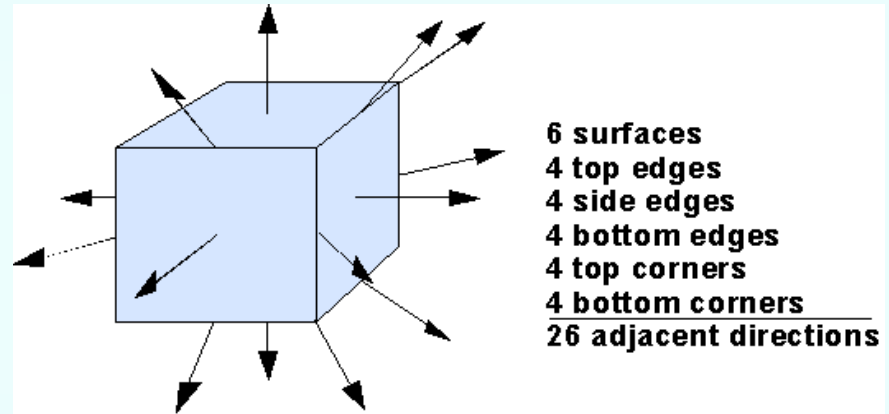
# Most Physical Systems Can Be Modeled Using 3-Dimensional Cells

## A 3-D matrix of cells



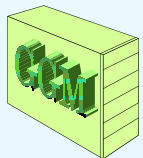
DiscreteSpaceModels 09/02/15

A single resource is shared between the adjacent face of each major cell



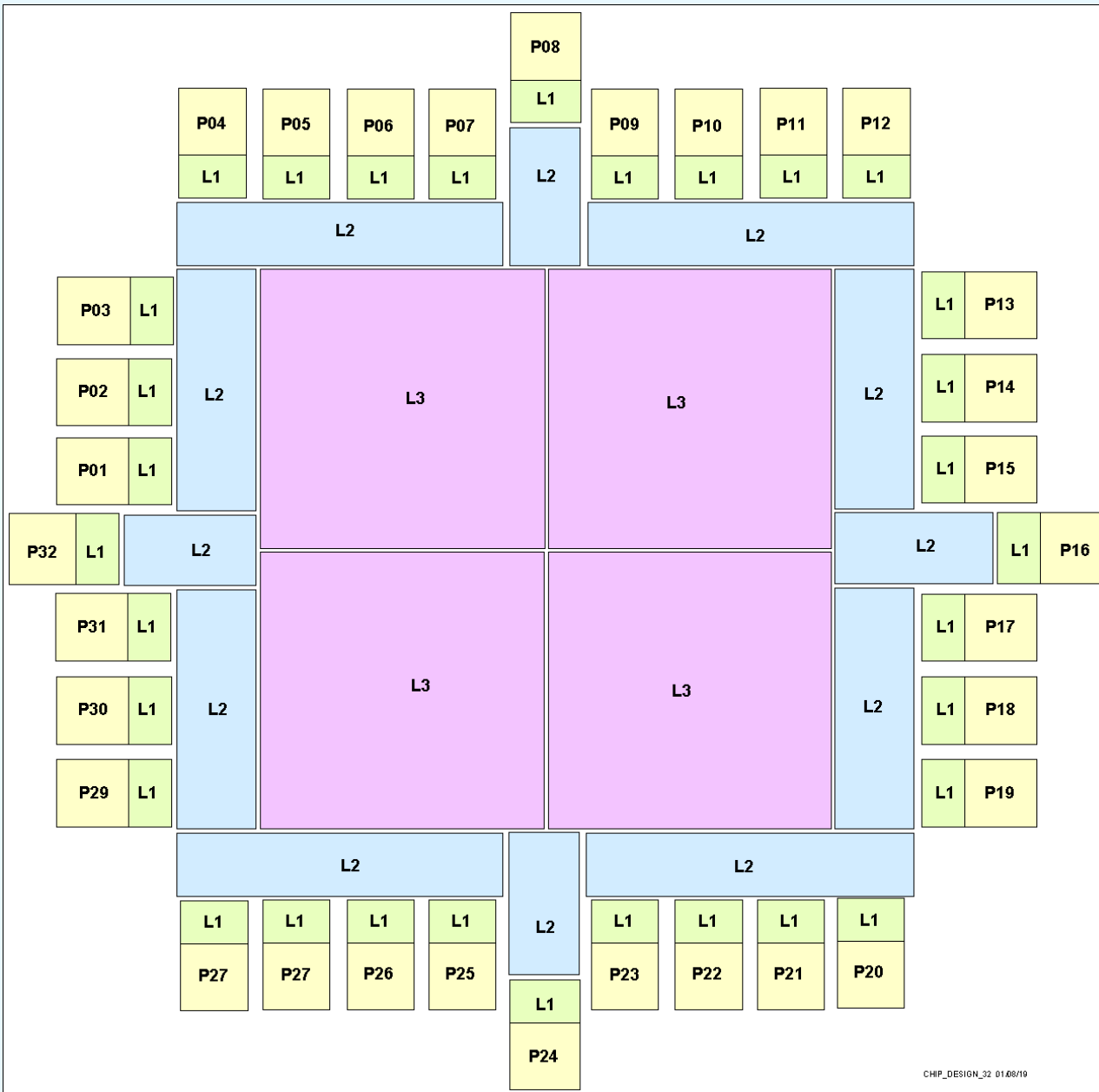
Each cell may contain huge numbers of minor sub-cells

**Cells need only interface with adjacent neighbors!**

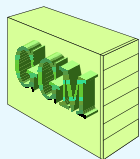




# CAD for Prediction & Control Systems



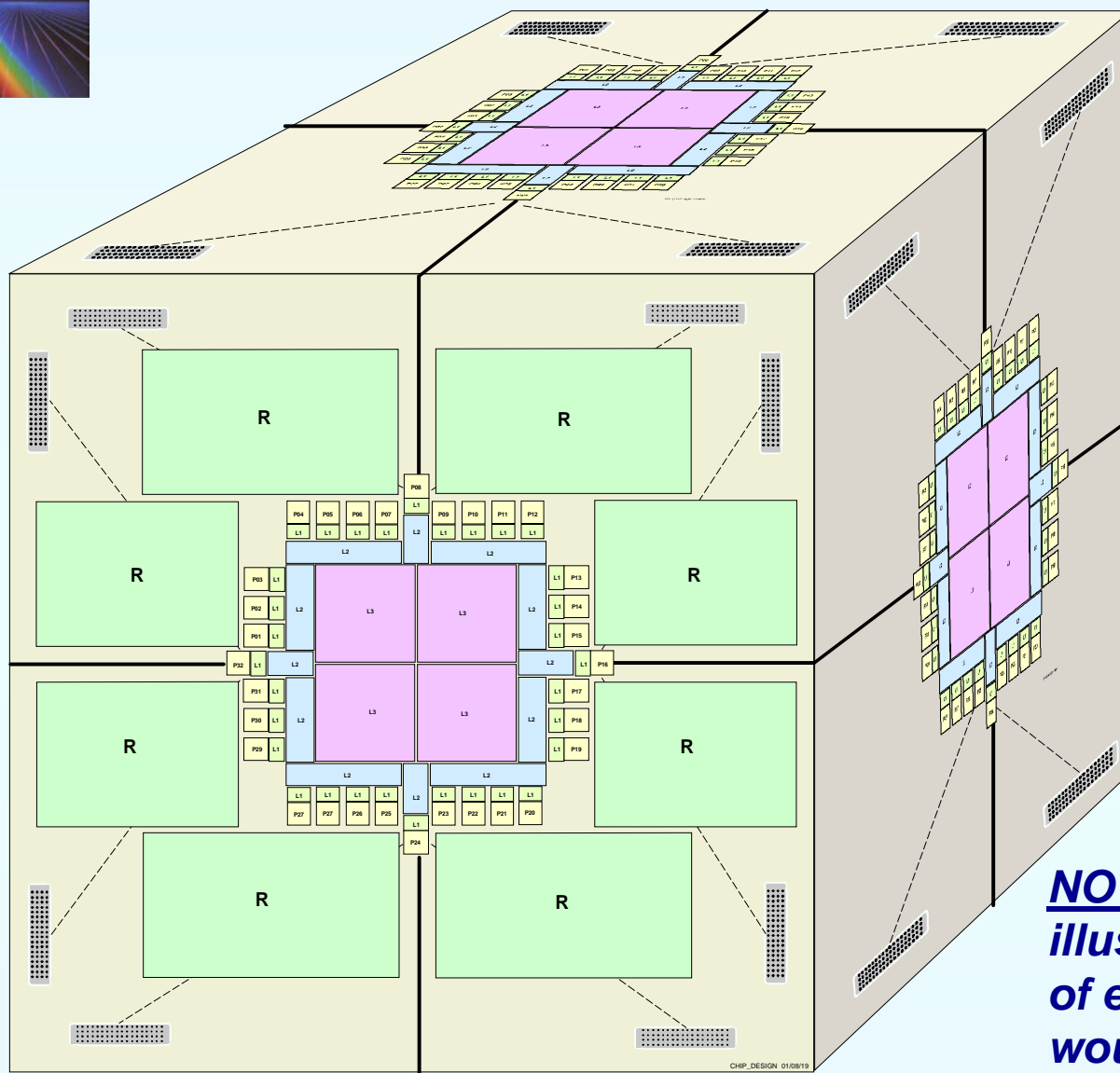
**Start with  
the basic  
Chip  
design  
- Greatly  
Simplified**



CHP\_DESIGN\_32 01.08/19

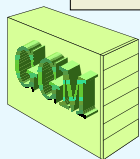


# CAD for Prediction & Control Systems



**Then use the  
3-D Box  
Design  
-  
with all  
DMA Channels**

**NOTE: This drawing only illustrates relative placement of elements - not where they would reside! For example, chips will be located on the inside of the boards.**



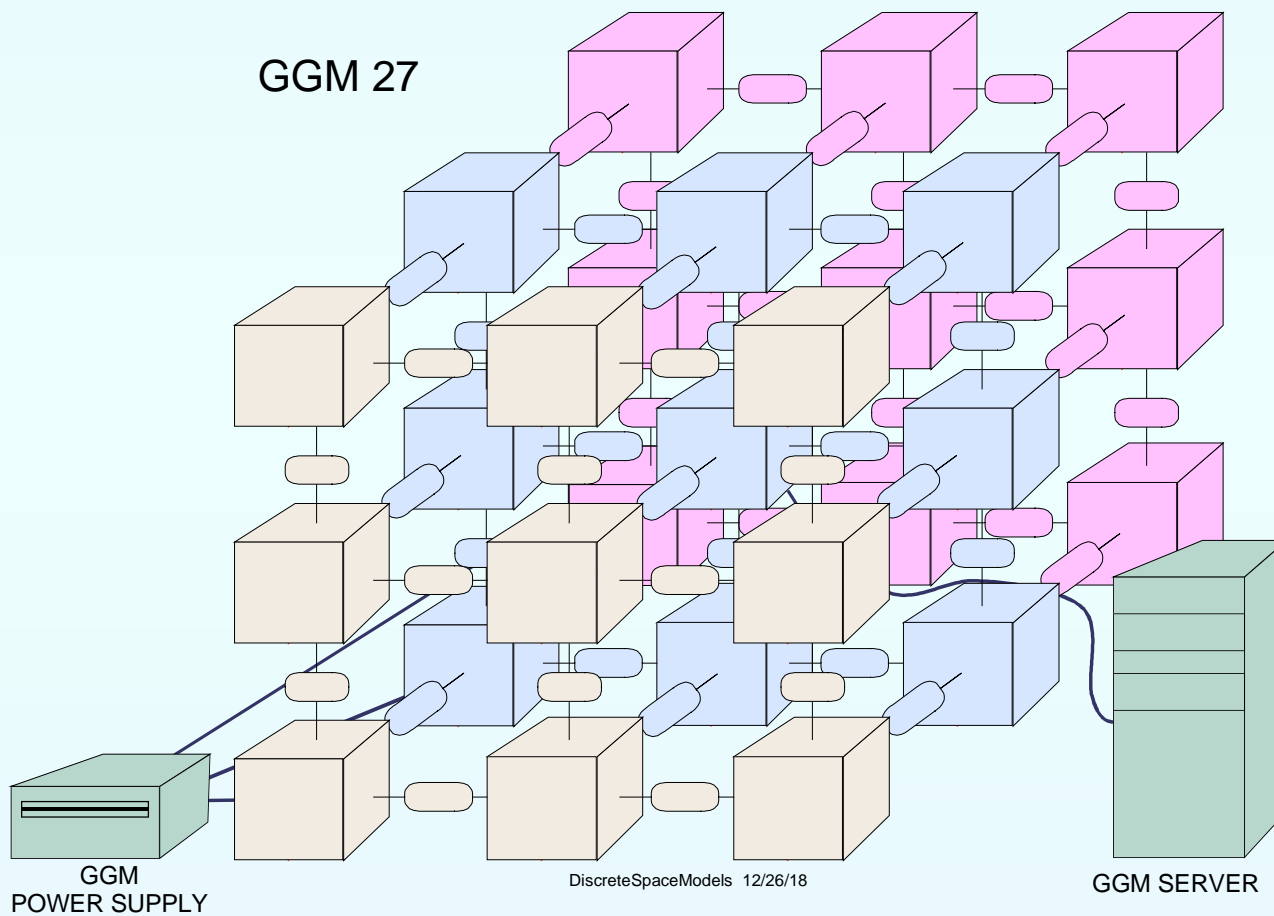


# CAD for Prediction & Control Systems

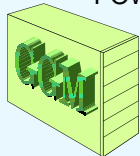


BASED ON THE:

## APPLICATION SPACE ARCHITECTURE



*Just  
Interconnect  
the boxes  
- In 3-D  
- With all  
DMA Channels*

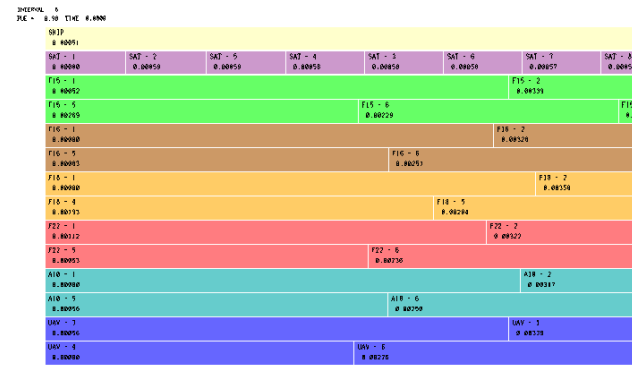
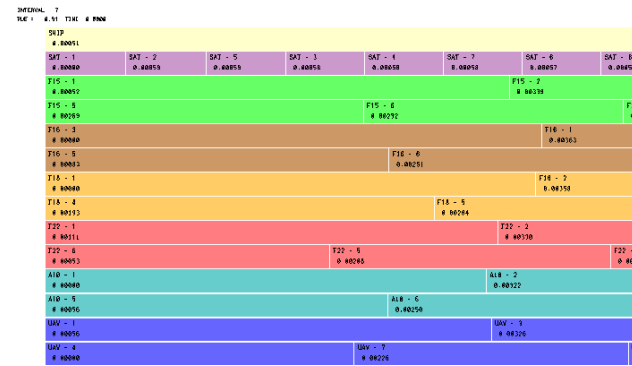
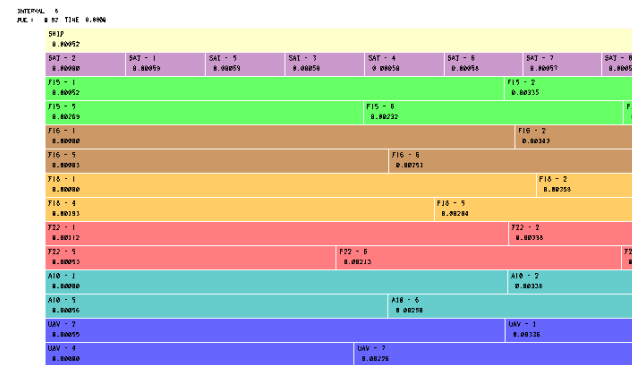




# CAD for Prediction & Control Systems



Scenario Topology

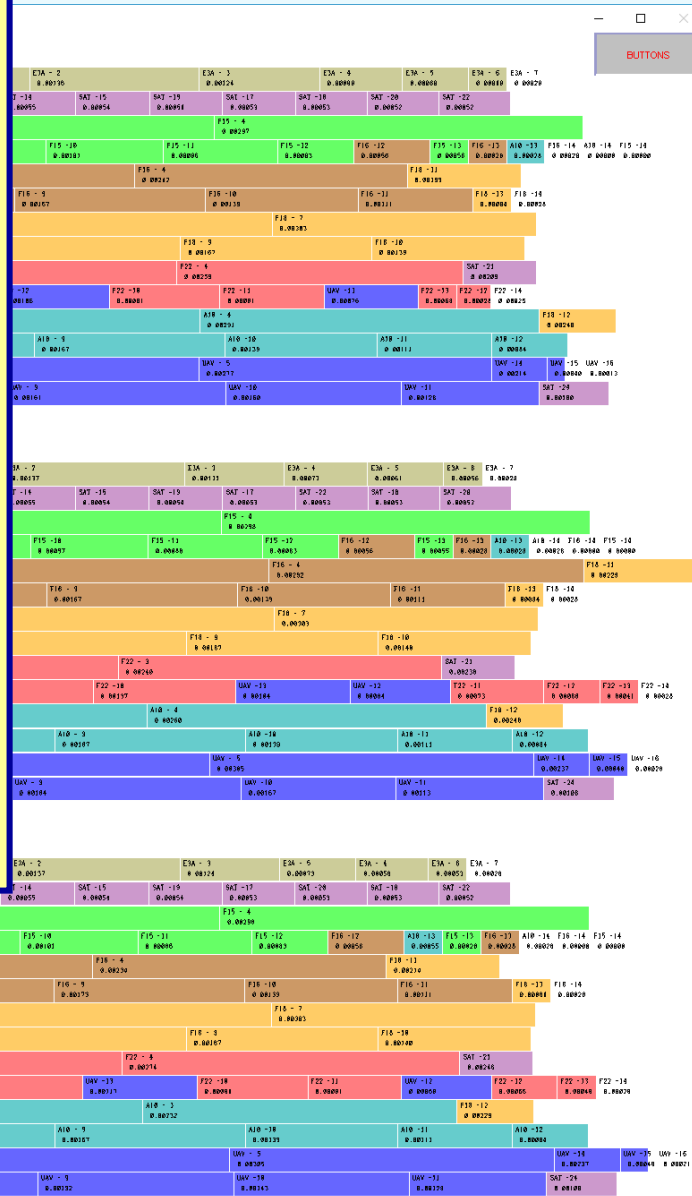


## GLOBAL PLANNER

153 Platforms  
12 Hour Scenario  
Single Processor  
24 Seconds

## TIME PROFILER

14 Processors  
2 Seconds  
Using instanced models,  
one can achieve  
> 95%  
Processor  
Utilization  
Efficiency (PUE)



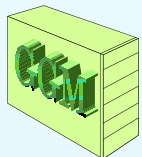


**Consider a comparison of Green Gene Machines with other Parallel Processors**

Green Gene Machine	Number of Processors	Power (KW) Consumed	Equivalent* Processors	Power (KW) Consumed
Green Gene 1	32	0.6	3200	12
Green Gene 2	64	0.8	7000	25
Green Gene 3	128	1.2	16000	60
Green Gene 01	192	4.0	50,000	188
Green Gene 04	768	16.0	400,000	1,500
Green Gene 09	1728	36.0	1,600,000	6,000
Green Gene 27	5184	108.0	5,000,000	18,750

**Then just look at the energy savings from the reduced number of processors**

**\*Equivalent Processor differences depend upon applications**





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