



# EquiPSim: Hands-On Training in Semiconductor Equipment and Process Behavior



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## OUTLINE:

- Motivation - Simulation for Engineering and Education
- Architecture
- Learning System Environment and Tools
- Authoring
- Applications
- Conclusions



# Acknowledgements



## Rubloff group

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## CEBSM, U. Arizona

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# Physically-Based Dynamic Simulation for Engineering and Education



- Powerful engineering applications for simulation, supported by commercial software and popular platforms
- Validated dynamic simulators reveal time-dependent behavior critical to semiconductor manufacturing equipment, process, sensor, and control behavior
- Applications to engineering design, control, optimization, and mechanistic insight
- Applications to broad spectrum of education and training, from novice to practicing engineer
  - *Huge need in industrial training*
  - *Conventional training is highly labor-intensive, limited-term impact*



# Motivation



**Simulation is a powerful engineering tool, but usability is increasingly limited as complexity and validity increases**

**User interface design is crucial to usability and effectiveness**

**Simulation could provide active learning experiences which enhance education and training**

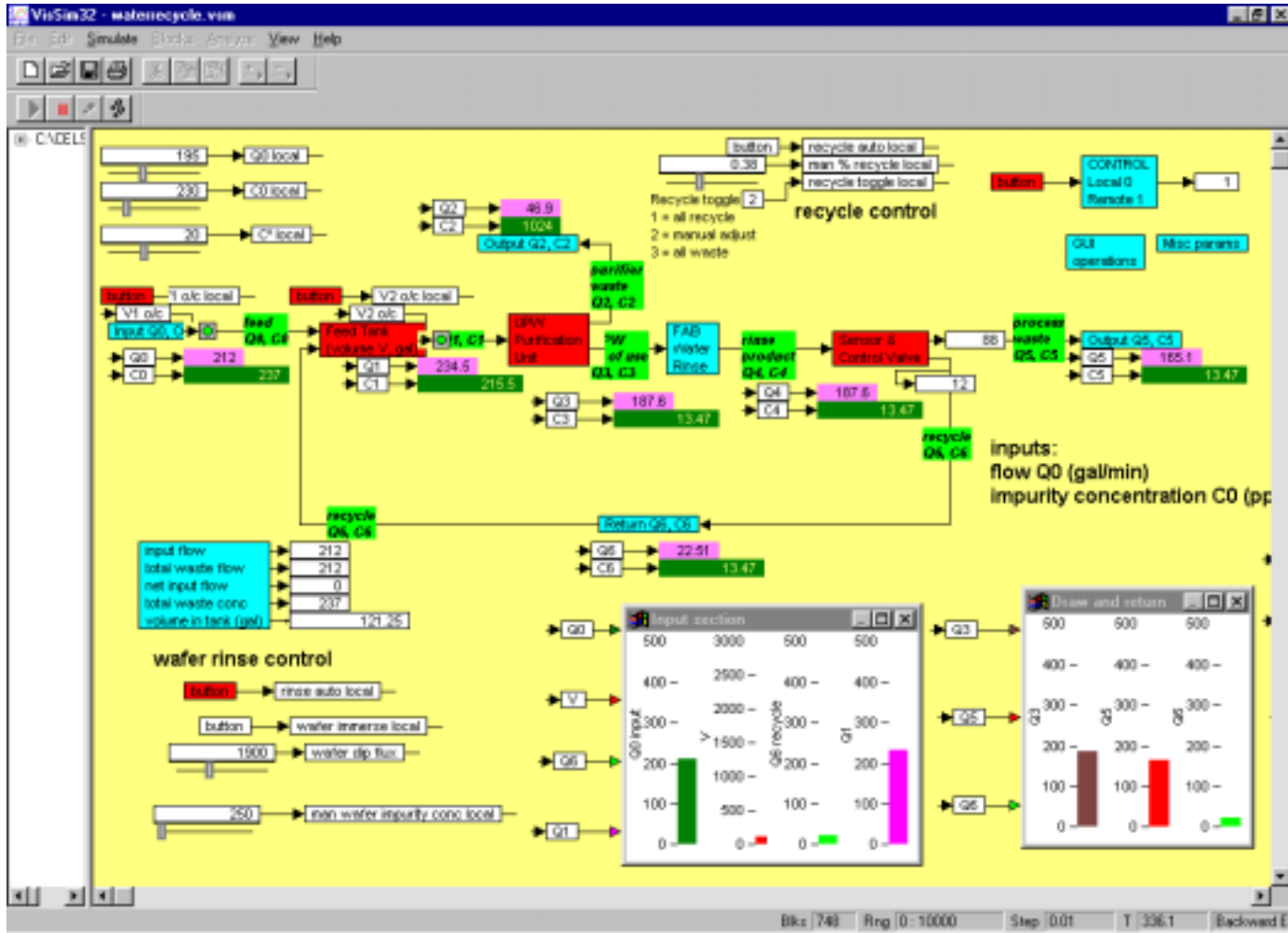
**Simulation must be encapsulated in a rich exploratory environment for effective learning at any/all levels**

## *Engineered Learning Systems*

- effective user interface designs
- simulation experiences for active learning
- closely coupled guidance material
- software tools as learning aides
- easy authoring
- educational continuum
  - *novice to expert*
  - *classroom to on-the-job*



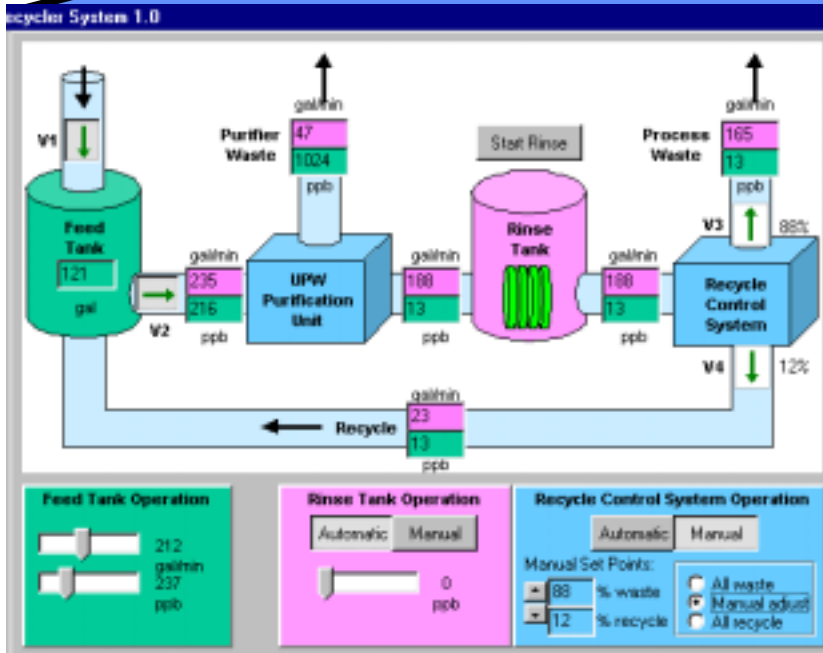
# Dynamic Simulator



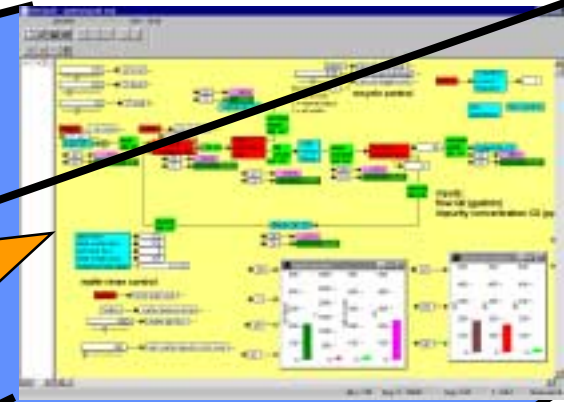
Commercial VisSim PC simulation platform (Visual Solutions Inc)



# Enhanced User Interface for Learning



DLL dialog



**Dynamic simulator**  
(VisSim simulation platform tool)

**Enhanced user interface**  
(Delphi visual development platform)



# EquipSim Learning Modules



**CONTROL BAR**

**FOCUS WINDOW**

**GUIDANCE WINDOW**

**HEAT TRANSFER MODULE**

**What's new ...**  
[Is the heat transfer module](#)  
[Water heating panel](#)  
[Water heating monitor](#)

**Heating methods**  
[Lamp heating of water](#)  
[Substrate heating of water](#)  
[Setting water temperature directly](#)

**Lamp heating of water**

Water heating can be accomplished by using high power [heating lamps](#) to direct light (optical radiation) onto the water through a transparent [window](#) on the process chamber. Lamp heating is particularly important for use in rapid thermal processing (RTP), in which the high radiative power of the lamps (kilowatts) can cause the water to heat rapidly (in a few seconds) to temperatures as high as 900-1000C. Typically, quartz halogen lamps are used to illuminate the water.

To achieve rapid water heating for RTP, the wafer must essentially be thermally isolated from its surroundings (e.g., held in just a few points, or by a ring). This produces an advantage in thermal cycling of the wafer, since less time is required to establish elevated temperature process conditions. However, with the wafer thermally isolated, the primary mechanism for wafer cooling after the process is radiative heat loss, followed by slow conductive or convective heat loss at lower

# Guidance Highlighter

**Graphical elements associated with technical term are highlighted in focus window**

**Focus Window**

**Guidance/Tutorial window**

**Cursor placed over technical term in guidance window**



The screenshot shows the 'Gas Flow Simulation 1.0' interface. The top part features a schematic diagram of a reaction chamber system. On the left, a pink cylinder labeled 'SiH4 Reactant Gas' is connected to a 'SiH4 MFC' (Mass Flow Controller) set to 400 sccm. This is followed by an 'MFC DSV' (Differential Shut Valve) and a 'Throttle Valve' (V2.8) set to 0%. The gas then enters a 'Reaction Chamber' containing a green oval. To the right, an 'N2 Vent Gas' cylinder is connected to the chamber via a 'V2' valve. Below the chamber is a 'Turbo Pump' with a 'Turbo Pump Switch' and a 'Bypass Valve' (V2.3). A 'Mech Pump' (Mechanical Pump) is also shown at the bottom left. The right side of the interface displays a 'Pressure History (torr)' graph with a logarithmic y-axis ranging from 1000 to E-05. A horizontal line at 1 atm is shown. The graph shows a pressure drop over time, with a 'T' marker at approximately 10^-3 torr. The simulation status at the bottom is 'SIMULATION IS RUNNING'. Below the status bar are buttons for 'Restart', 'Continue', 'Stop', 'Display Options', 'Print Param Log', and 'QUIT'. The bottom section contains 'Parameter Settings', 'Comments', and 'Parameter Log'.

Learner experiments freely with system design parameters

Learner annotates results of experiments into lab notebook

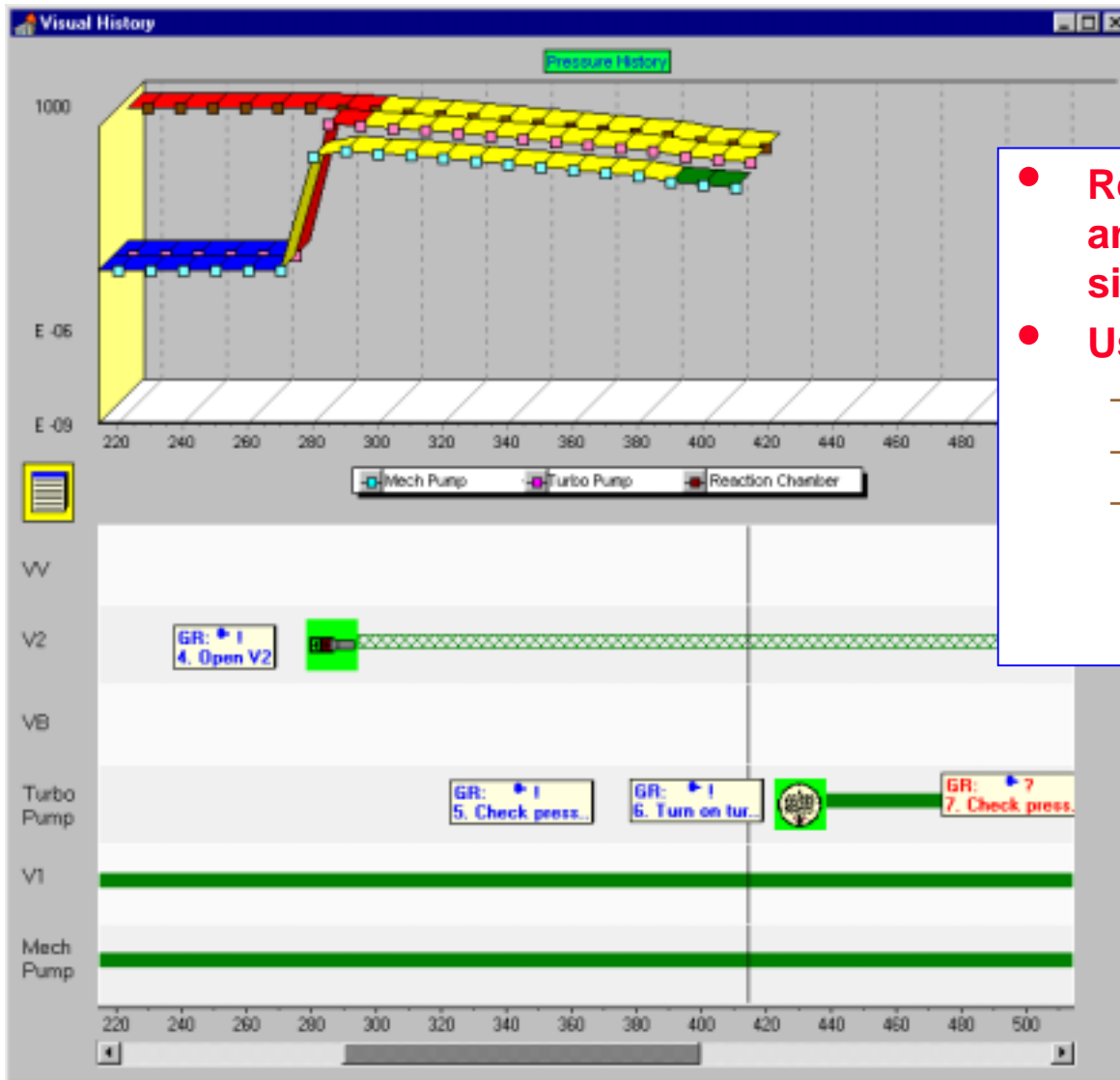
Lab notebook:

- automatic date/time and parameter settings
- learner's comments

Print lab notebook



# Learning Historian Record of Events



- Record, revise, replay, and annotate event histories in simulation experiments
- Use for
  - *tutorial generation*
  - *questions to teacher/expert*
  - *peer collaboration*



# Learning Historian Replay of Simulation



History Editor - C:\CELS\Learning Historian\Mulpumpan.his

Action

Restart

Continue

Stop

---

History

Restart

Load

Save

Close

Hide

Comments

---

Misc

Timer

Options

Email

Print

Quit

Pressure History (torr)

Elapsed Time

Guidance Historian Lab Notebook Developer Kit

**Goals**

[Using the system](#)

[Pump system introduction](#)

Pumpdown using:

- mech pump through bypass
- Demo 1: Mech only
- mech pump through turbo
- mech and turbo pumps
- Demo 2: Mech & Turbo

[Visual Historian Exercise](#)

**Pumpdown**

[Turbo pump](#) [Turbo pump on](#)

In Pumpdown 1, you use the turbo pump. This has two limitations:

- Typically the bypass line takes a long time to apply, so it takes a long time to apply sufficient reactive species (e.g., water or hydrocarbons from previous air exposure).
- The base pressure achievable with only the mechanical pump is not low enough to remove sufficient reactive species and achieve low enough base pressure in the reaction chamber to

From: GR

2. Open V1

Here we opened valve V1 so that the mechanical pump operates to pump down the turbo pump volume.

OK



# Simulator: Local and Remote Control



**Local / Remote Control**

Simulator control:  
red (0) if local  
green (1) if remote (VB GUI)

**Local/remote control switch on simulator:**

- Local** - simulation controlled by “actuators” on simulator itself
  - Useful for engineers with domain knowledge
  - Enables continuous improvement of simulator’s physical fidelity
- Remote** - simulation controlled by “actuators” from user interface
  - Allows simulator control from user interface
  - Removes need for interface designer to have domain knowledge



# Authoring - User Interface



**Simulation Parameter Setup**

Name	Default Value	VSIn #
Chamber volume (liters)	10	7
Mech pump speed (l/s)	15	8
Turbo pump speed (l/s)	360	9
Bypass conductance (l/s)	1.5	10

Buttons: Add, Modify, Delete, OK, Cancel

Bottom Panel: Restart, Compute, Stop, SIMULATION IS...  
 Guidance | Simulation Parameters | Developer Kit  
 General Instructions | Education Content  
 Guidance URL: C:\CELS\GasFlow\pl\html\start\_simulation.htm  
 Simulation Viewer: C:\Program Files\...  
 Simulation File: C:\CELS\...  
 Buttons: Simulation Parameters Setup, Email Setup

Developer kit provides authoring instructions and flexibility to change pointers

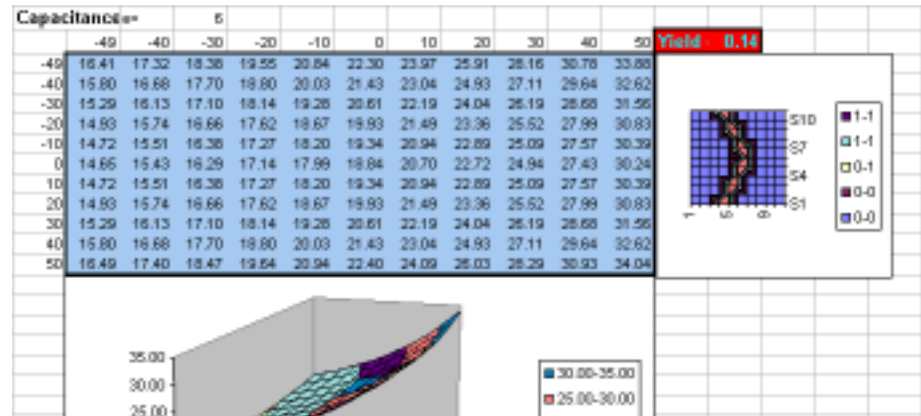
Developer's pop-up facilitates definition of system parameters to be integrated on simulator and user interface sides



# Process Integration and Yield Modeling



- Expand learning systems to support Excel models
- Process integration example completed (simple device)
- Cost/performance modeling in other industries

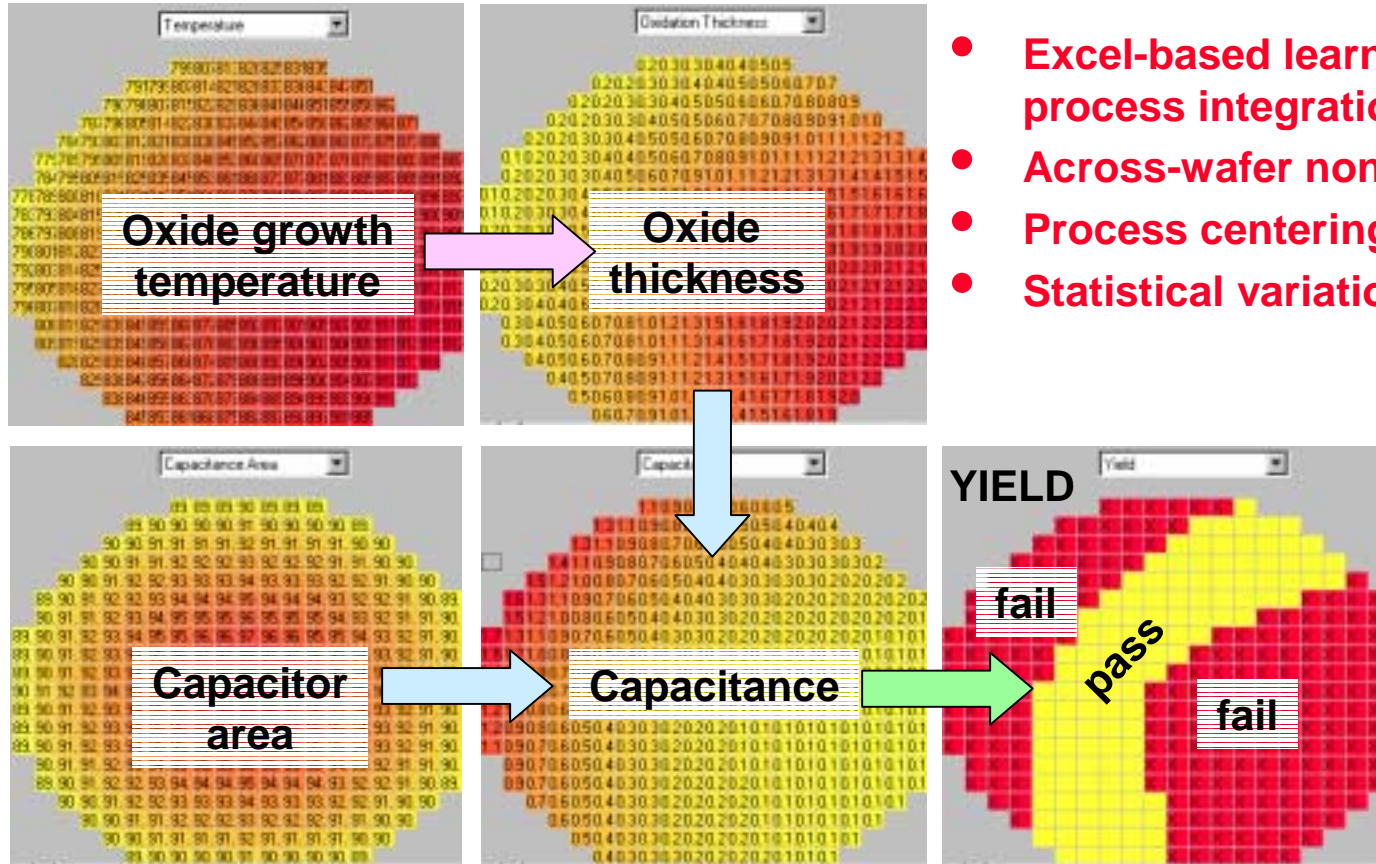


The screenshot shows a software interface with several sections:

- Center (°C):** 900
- Gradient (r):** 5
- Gradient (x):** 6
- Gradient (y):** 3
- Growth Time:** 11
- Cap Area Profile:**
  - Center (cm<sup>2</sup>): 100
  - Gradient (r): 1
  - Gradient (X): 0
  - Gradient (Y): 0
- Capac limits for Yield:**
  - Min (pF): 0.25
  - Max (pF): 0.6
- Statistical Variation:**
  - Temp SD: 15
  - Temp Center: 0.0
  - CapA SD: 15
  - CapA Center: 0.0
- Color Selection:**
  - Linear Shading: 776.798 (yellow), 870.355 (orange), 824.577 (red), 917.521 (dark red)
  - User Set Colors: 0.18102 (yellow), 1.62091 (orange), 0.90096 (red), 2.36267 (dark red)



# Process Integration and Yield Modeling



- Excel-based learning system for process integration and yield
- Across-wafer nonuniformity
- Process centering
- Statistical variation



# Center for Engineered Learning Systems



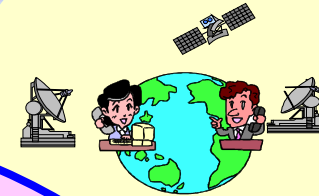
**CELS**

[www.isr.umd.edu/CELS/](http://www.isr.umd.edu/CELS/)

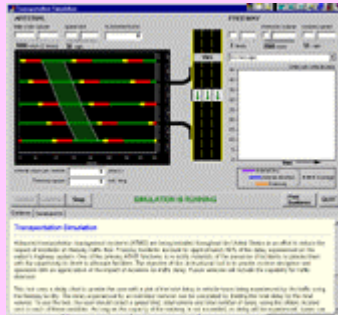
**Portable, standalone**



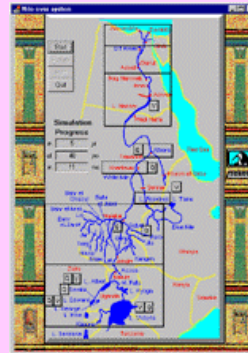
**Internet-connected**



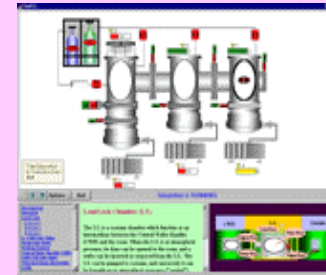
## APPLICATIONS



**Systems  
management**



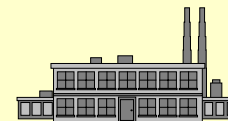
**Politics, history,  
economics, and  
society**



**Science and  
technology**

**Individual  
and group  
active learning  
experiences**

**Real-time and  
asynchronous  
collaboration and  
counsel**



**At work, in school, and at home**

CELS is administered as a Center within the Institute for Systems Research, an entity of the A. James Clark School of Engineering at the University of Maryland.





# Conclusions



- **High quality user interface design** expands value of simulation to engineering and education
- **Effective engineered learning systems combine**
  - Simulation with good user interfaces*
  - Tightly coupled guidance materials*
  - Software learning aides*
  - Tools to facilitate experimentation and collaboration*
  - Easy authoring for both domain knowledge and software environment*
- **EquiPSim learning modules**
  - Prototypes available ([www.isr.umd.edu/CELS/](http://www.isr.umd.edu/CELS/))*
  - Vacuum, gas flow, heat transfer, chemical reactions*
  - Statistics, optimization, process control*



# BACKUP



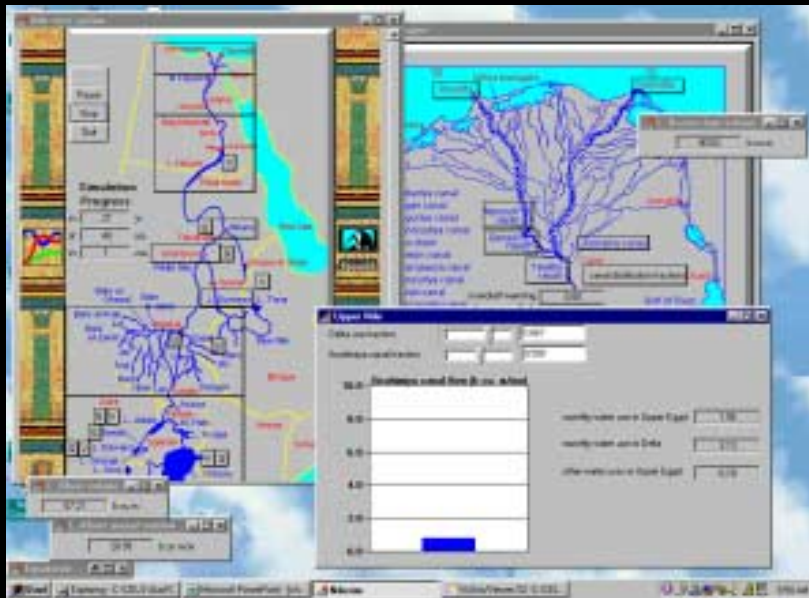
# Other Simulator-Based Learning Systems



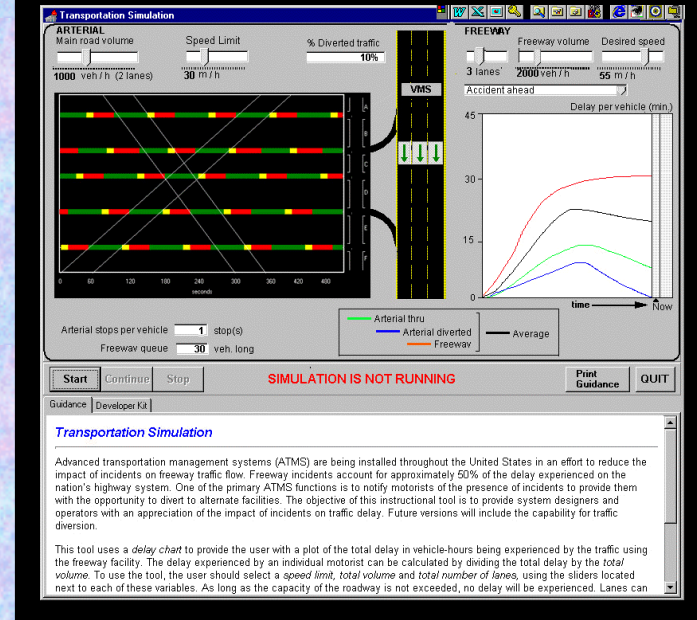
## CELS

[www.isr.umd.edu/CELS/](http://www.isr.umd.edu/CELS/)

## NileSim



## TrafficSim





# EquiPSim: Hands-On Training in Semiconductor Equipment and Process Behavior



We have developed EquiPSim (Equipment and Process Simulation), a software-based learning system for semiconductor manufacturing aimed at providing active hands-on experience in vacuum and gas flow technology, heat transfer mechanisms, chemical reaction processes, process control approaches, and optimization strategies. A validated simulator engine constructed under commercial PC-based dynamic simulation software (VisSim™) expresses physically-based time-dependent response to variations in the equipment controls represented, allowing the user to operate the system freely and observe realistic responses. Visualization of the system is accomplished through an enhanced graphical user interface, built on a Delphi v/4 visual development platform. This platform then becomes an engineered learning system by incorporating not only an improved visual representation of the system, but with a host of user-controllable learning aides, including: a guidance section of hypertext, accessed locally or over the Internet; active links between the guidance materials and the visual system representation; tools for modifying system design parameters; a lab notebook for recording design parameter sets along with annotation of results of user experiments; facilities for distance collaboration; and a learning historian for recording, reviewing, revising, and replaying action sequences. The content is aimed at both novices and more experienced engineers (depending on concept being treated). The software architecture is structured to facilitate separable authoring, in which the domain expert need concentrate only on the physical fidelity of the simulator and the guidance concepts to be taught, while the user interface is built from templates and predefined application objects.

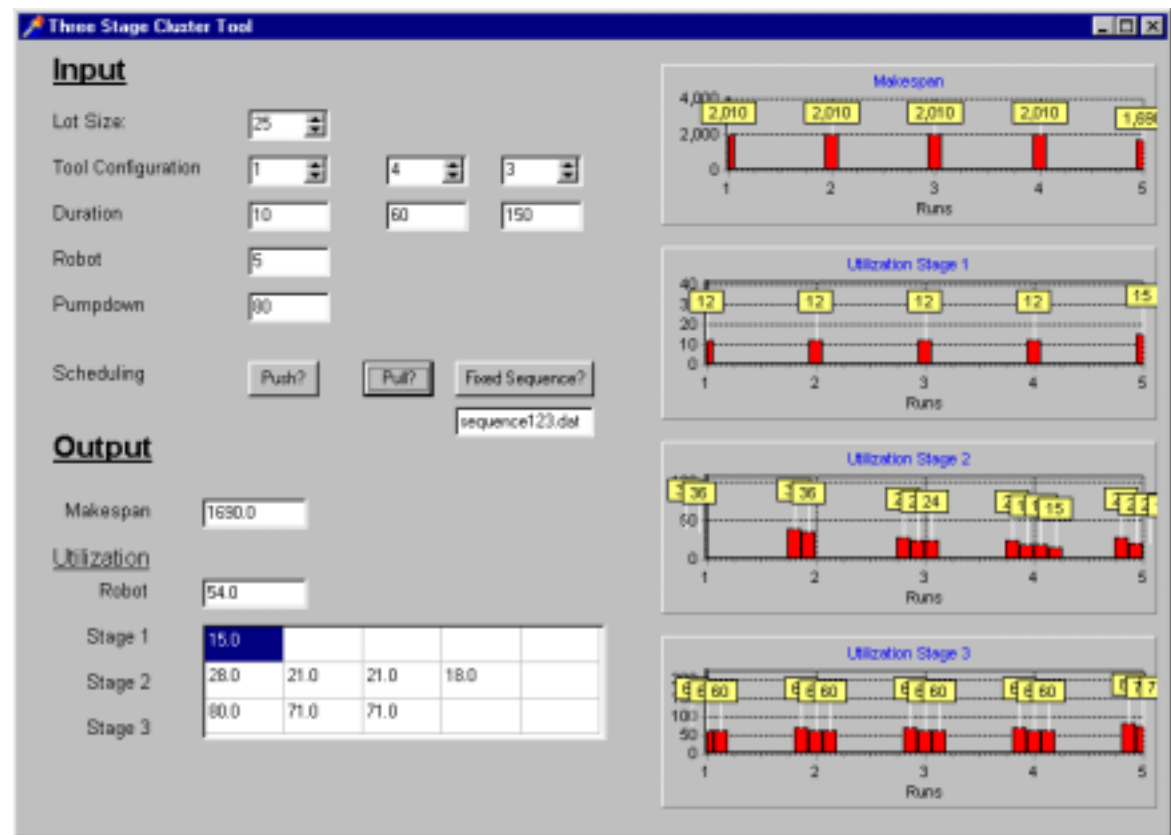


# Discrete Event Simulation and Factory Operations



- Expand learning systems to support legacy code (Fortran, C/C++, ...)
- Cluster tool simulator (logistics, scheduling) - implemented in Java, now incorporated into engineered learning system

- Factory operations simulator (Factory Explorer), consisting of Excel front end which drives simulation engine, now incorporated into engineered learning system





# Simulator-Based Manufacturing Education and Training for Microelectronics Processing



- **NSF grant EEC - 9526147, 9/15/95 - 8/31/00, PI G. W. Rubloff, \$600K**
- **Goal**
  - *Develop and assess methodologies in which physically-realistic simulation tools can be incorporated into broader software-based learning environments which are available anytime, anywhere, and which can provide value not only for experienced engineers, but also for manufacturing operators or technicians with little relevant technical background*
- **Manufacturing Training Modules - for operators, technicians, and students with little technical background**
  - *Vacuum-Based Process Equipment*
  - *Heat Transfer*
  - *Chemical Processes*
- **Engineering Design Modules - for practicing engineers and graduate students**
  - *Statistics and Design Optimization*
  - *Process Control*



# Simulation-Based Learning Systems for Environmentally-Benign Semiconductor Manufacturing



- NSF grant EEC, 10/1/99-9/30/02, \$400K
- PI G. W. Rubloff (U. Maryland ISR), Co-PI F. Shadman (U. Arizona CEBSM)
- **Goals**
  - *Education modules at 3 levels: undergraduate, graduate, practitioners*
  - *Incorporation of legacy simulators*
  - *Simulation explorer*
  - *Educational assessment*



# Wish List for ESH Learning Systems



- **User-driven system design**
  - *Choose individual system components*
  - *Expand and reconfigure network*
- **Exploit existing models and simulations**
  - *Utilize existing codes directly (Fortran, ...)*
  - *Generate compact models in simple, systematic fashion*
- **Facilitate design and optimization of control system**
  - *Incorporate various control systems elements*
  - *Experiment with optimization and fault management algorithms*
  
- **Build the basis for systems design and optimization**
  - *Educate new practitioners*
  - *Support systems engineering for current practitioners*