# Plant Simulator

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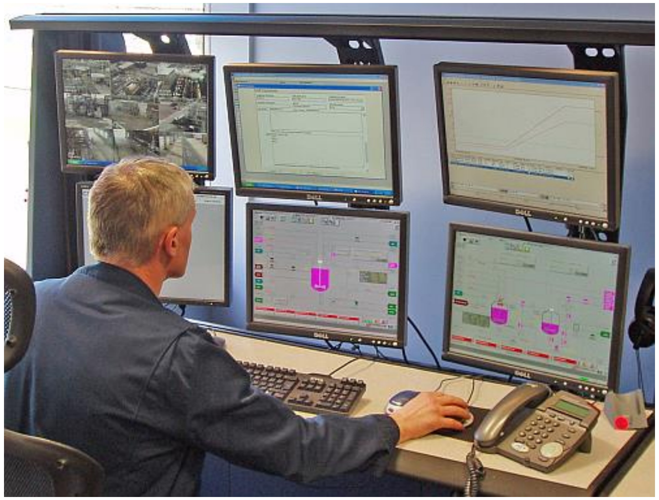
# Introduction to plant simulation

- **Dynamic Process Simulation**
- **Dynamic Accident Simulation**
- **Dynamic coupling**: Process and Accident Simulation
- **Immersive Virtual Reality** (IVR)
- **Augmented Virtual Reality** (AVR)

# Dynamic Simulation

- **From steady-state process simulation…**
  - Design of industrial processes
  - Qualitative and Quantitative Risk Analysis
  - HAZOP, Event, and Fault Tree Analyses, ….



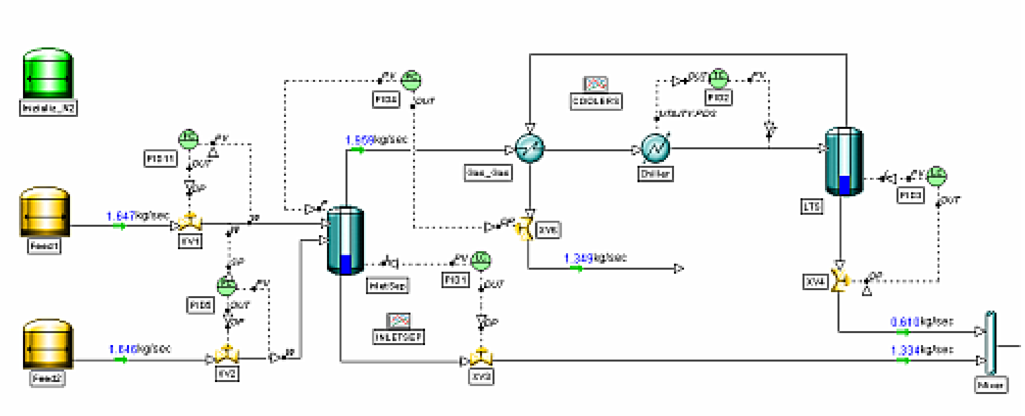
- **…to dynamic process simulation for:**
  - process design
  - process understanding
  - *a priori* inspection of control loop alternatives
  - effectiveness of start-up and shutdown procedures

- SimSci-Esscor (**Dynsim**)
- Honeywell (**UNISIM**)
- Aspentech (**aspenONE**)
- PSE (**gPROMS**)
- CreateaSoft (**Simcad**)
- …

# Dynamic Simulation features

- **Rather high cost** for the annual license of the DS
- Rather **high number of hours** of a team of specialized engineers
- **Reduced set** of operating conditions

- A DS study is **usually commissioned by the plant buyer to**:
  - understand and assess the design quality
  - verify a priori the control structure and performance respect to external disturbances
  - analyze the process behavior under nominal and off-spec operating conditions




# Operator Training Simulation

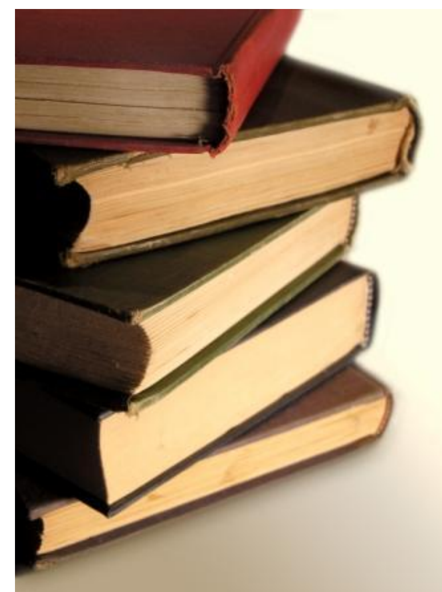
- **Conventional Operator Training Simulation**
- From the design realm to the **on-line** process control domain

- The main reason for OTS is **training the operators from scratch**
- Training of specialized manpower
- Usually **focused on control-room operators'** training

- Important for simulating both rare and unconventional events:
  - off-spec conditions
  - grade changes
  - start-up and shutdown procedures
    - planned shutdown
    - emergency shutdown

# Operator Training Simulation

- **Need for <u>field operator</u> training**
  - conventional OTS are not so good at training field operators
  - **Conventional OTSs are not capable of simulating accident events**
  - Need for a dynamic process simulation of industrial accidental events
  - **Coupling of Dynamic Process and Accident Simulation**



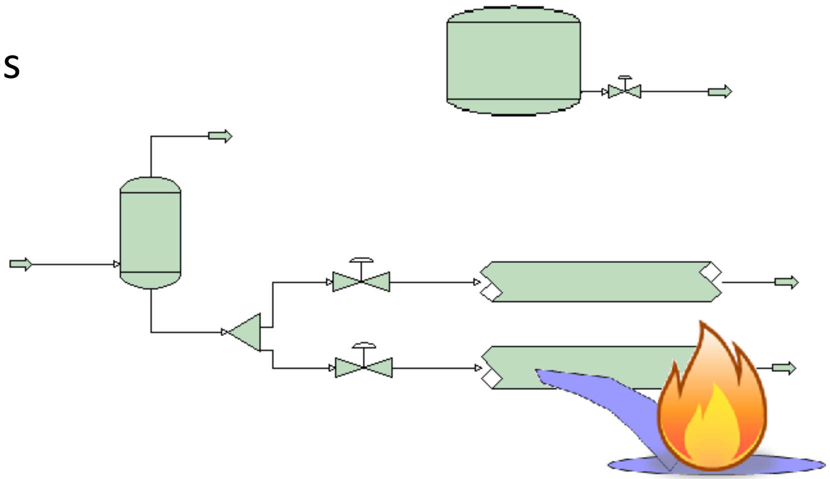
# Triggering events

Data analysis from **FACTS** archive on 216 **industrial accidents**

| Triggering event | % |
|---|---|
| Design error | 1 |
| External causes | 3.5 |
| Wrong or defective assembly | 6 |
| Incorrect procedures, inadequate operating conditions | 6 |
| Runaway reactions, products instability | 7.5 |
| Unsuitable materials | 8.5 |
| Malfunction of alarms, protection devices, service lines | 9.5 |
| Process errors (overpressure, overloading) | 26 |
| **Human errors** | **32** |

# Operator Training Simulation

- **Dynamic Accident Simulation**
  - Emission of liquid, gas and liquid/gas streams
  - Pool spreading and shrinking on soil and water
  - Pool boiling and evaporation
  - Ignition of the pool and pool fire
  - Jet stream and jet fire
  - Fireball, Unconfined Vapor Cloud Explosion, …
  - View factors between the fire and the surrounding process units
  - Quantification of radiative heat fluxes towards the nearby units
  - Dispersion of dense gases in complex environments
  - …



# Simulators coupling

**Dynamic Process Simulator**

$$\dot{m}_L\left(t_n\right),\dot{m}_V\left(t_n\right),T\left(t_n\right)$$

$$Q_{irr}\left(t_n\right),\tilde{c}_i\left(t_n\right)$$

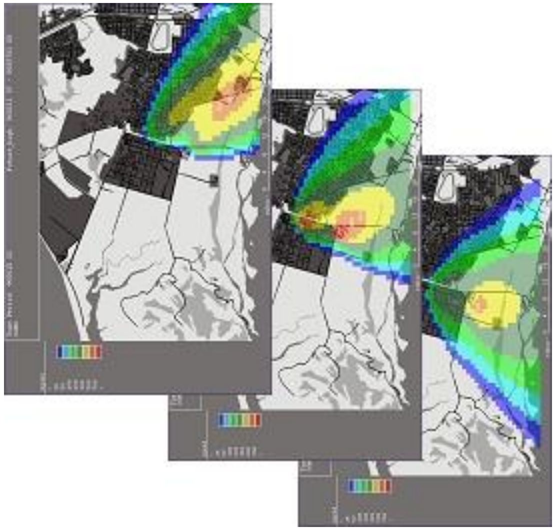
**Accident Simulator**

**DYNAMIC SIMULATION**

# Process and Accident Simulation

- **Benefits** of coupling Process and Accident dynamic simulators:
  - improvement of the operator knowledge
  - **analysis of very rare accidental events**
  - understanding of **process behavior under emergency**
  - quantitative evaluation of accidental outcomes
  - **slow-motion** and **fast-motion** analysis of accidental events
  - recording and playback of operator actions
  - **performance evaluation of operator actions**

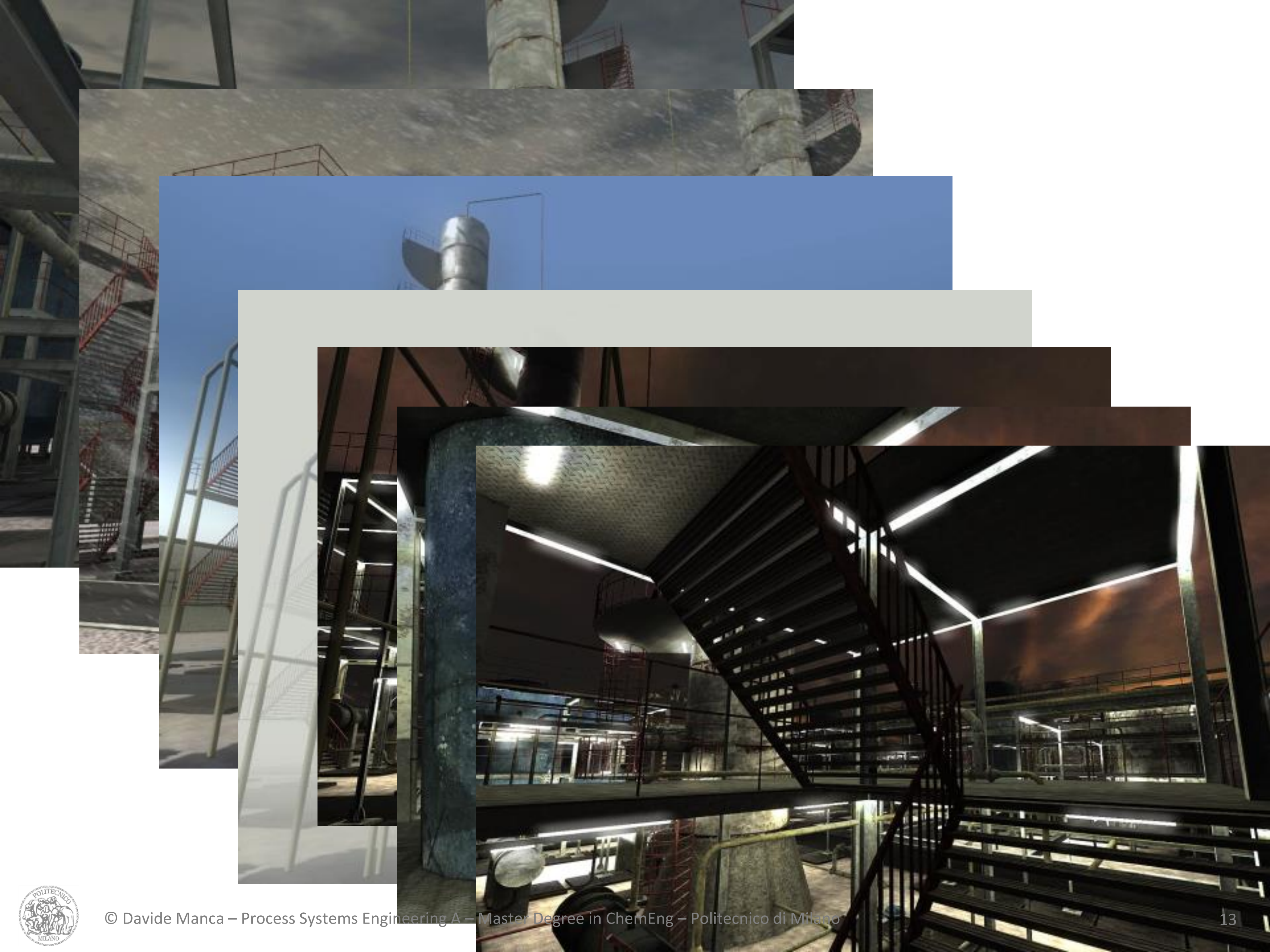
- **Outcomes**
  - Quantification and visualization of iso-radiative flux curves
  - Quantification and visualization of iso-concentration curves
  - Evaluation of the toxic absorbed dose at a point of the plant
  - …



# Immersive Virtual Reality

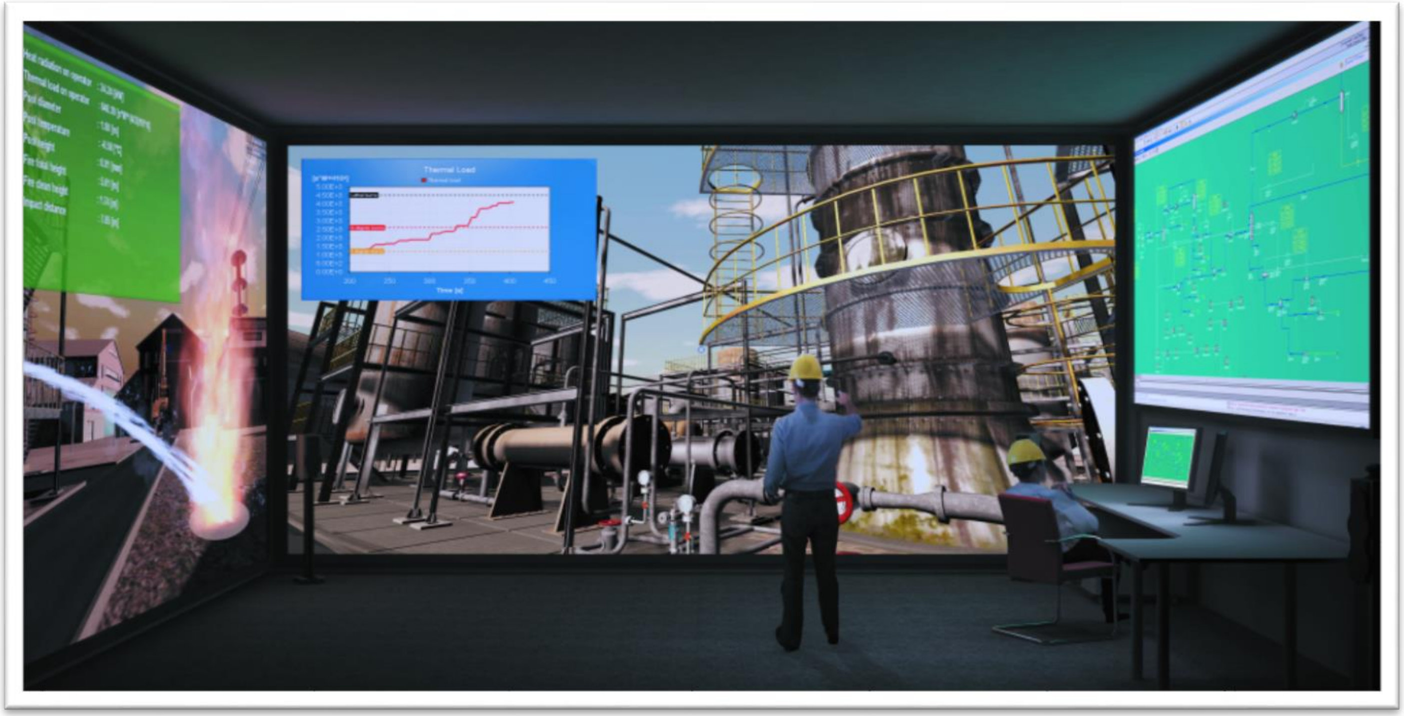
# Immersive Virtual Reality

- A **virtual reality** environment based on the real structure of the plant allows **increasing the immersivity** of the software:
  - full 3D visualization and rendering of the plant
  - immersive participation to:
    - **meteorological conditions**: wind, sun, light, night, fog, …
    - **spatial sounds** of process units
    - equipment materials and ground features
    - **High detail** of secondary equipment and plant features:
      - Valves, pumps, pipe rack, structures, …



# Immersive Virtual Reality

- The **operator is in front of a 3D stereoscopic environment** and moves through the 3D representation of the real plant
- The operator can **experience events and concepts** that a conventional OTS can neither simulate nor render



# Augmented Virtual Reality

# Augmented Reality

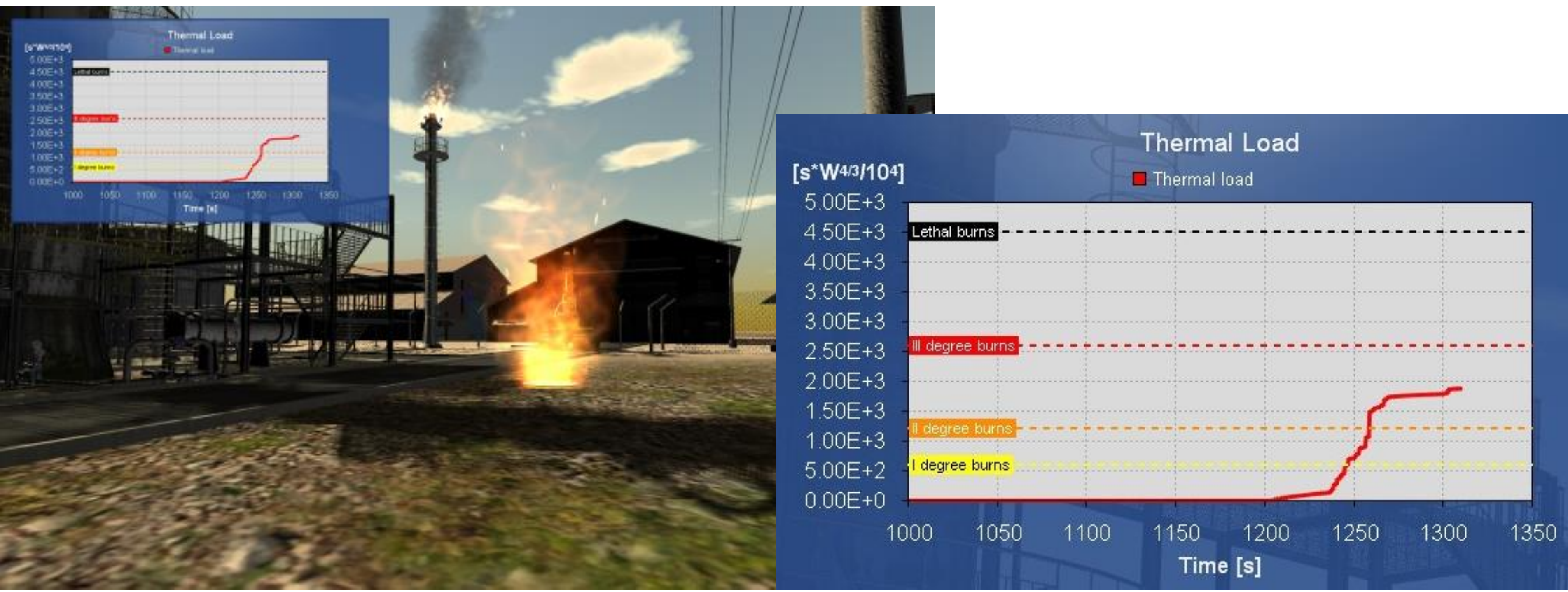
# Augmented Virtual Reality

Virtual Reality substitutes the real world,
Augmented Reality supplements it
(*Stedmon & Stone, 2001*)

- A step further in the training of field operators is adding to the 3D representation of the plant some **additional information that is neither visible nor available in the real world**.
- The dynamic process and accident simulator allows visualizing:
  - labels of process units, valves, pipes, …
  - level, temperature, pressure and concentration of process units
  - flowrates in the pipes
  - radiative heat fluxes from fires
  - concentration of released toxic substances

# Augmented Virtual Reality

- The **trainer** (either an automatic procedure or a human being) can activate or deactivate these data and test the efficiency of the **trainee** in:
  - **responding to an alarm**
  - **disentangling with respect to a toxic cloud**



# Augmented Virtual Reality

With reference to an accident event it is possible to **visualize**:

- a **toxic gas** cloud in terms of false-colors while it moves inside the plant
- the **isoconcentration curves** produced by a toxic release
- the **isoradiation curves** produced by a pool fire, jet fire, or fireball
- a diagram with the **alarm thresholds**

# Augmented Virtual Reality

- By tracking the operator path across the plant it is possible to evaluate the **breathed cumulative dose** and **measure his/her stamina**.
- According to several authors, the simulated interaction between men and machines is of paramount importance for risk prevention and risk assessment

- **Advantages**
  - **reduced learning costs**
  - reduced equipment maintenance
  - **increased transfer of training and knowledge**
  - **just-in-time operator training**

# Benefits of Digital Twins

- Safety
  - **Practice difficult procedures repeatedly until fully mastered**
  - **Experience process exercises in a safe environment**
  - Decrease operator anxiety in a controlled environment
  - Learn specific safe operating procedures; break bad habits
  - **Train anytime day or night**
  - Address any fatigue issues

- Production
  - Real process can operate without interaction with crews being trained
  - Reduced equipment maintenance and process stress
  - **Refine skills to improve productivity**

# Benefits of Digital Twins

– Profits
- **No real operating costs on the simulated process**
- No process-use hours
- **Train multiple operators, on multiple units, at one time**
- Possible benefits from lower insurance premiums

– Personnel
- Screen operator hires
- **Track operator training performance by built-in testing**
- Address ergonomic issues
- Preview process skill understanding and operation

# Performance Assessment

# Specifications

- First train and then assess
  - Assessment of single operator either CROP or FOP
  - Assessment of CROPs
  - Assessment of FOPs
  - Assessment of CROPs, FOPs, and Supervisor(s)

- The assessment should be:
  - **Automatic**
  - **Unattended** (*i.e.* no assessment from the trainer)
  - Validated
  - Consistent
  - **Unbiased**
  - **Repeatable**
    - The events triggering and the way they are measured must be replicable
  - Accepted, shared, transparent

# Specifications

- The operator assessment must take into account:
  - **Process-oriented features**
    - Dynamics knowledge
    - *Abnormal situation management*
    - Complexity level of the operating procedures
    - *Capability of responding to industrial accidents*
    - Equipment efficiency
    - *Operator performance*
  - **Human Factors**
    - Experience
    - Time devoted to training
    - Fatigue
    - Body indicators
    - Situation awareness
    - Preparedness

**Conventional OTS**

**Advanced OTS**

# Challenges

- We have to match qualitative and quantitative values to produce an overall assessment
- Besides the overall assessment the operator should receive also a detailed list of marks (pros and cons) about his/her actions
- We must find:
    - some **metrics** to transform both qualitative and quantitative measures into numbers → scaled values
    - a shared **methodology** to assign relative weights to the items that contribute to the final assessment
    - a **procedure** to transform qualitative data and evaluations into quantitative ones


# Challenges

- **Multidisciplinary approach** to the solution of the problem:
  - Chemical engineers
  - Safety engineers
  - Cognitive psychologists
  - IT experts
  - Human Factor engineers
  - Ergonomists

# Performance assessment procedure

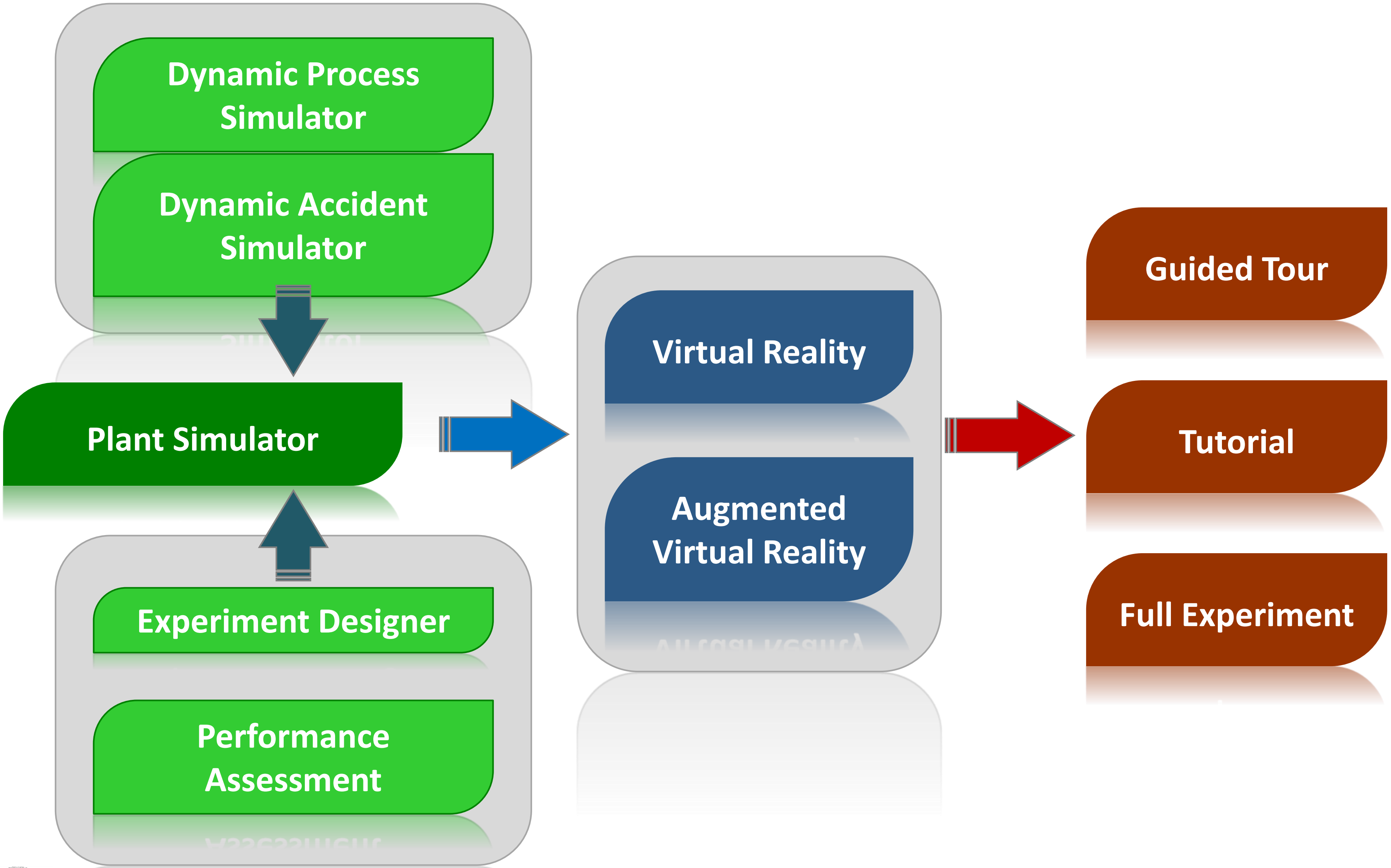
- On the **Process side**:
  - **Measure** some key process variables (*e.g.*, T, P, F, Q, …)
  - **Evaluate** derived quantities (pool volume, thermal load, …)
  - **Identify and evaluate** some Key Performance Indicators: **KPI**s
- Make the same for what concerns the **Human Factors**
  - **Measure** some key human/body variables (*e.g.*, heart beat, breathing rate, response time, …)
  - **Evaluate** derived quantities (*e.g.*, emotional involvement, process understanding, situation awareness, preparedness, …)
  - **Identify and evaluate** some Operator Performance Indicators: **OPI**s

# Final remarks

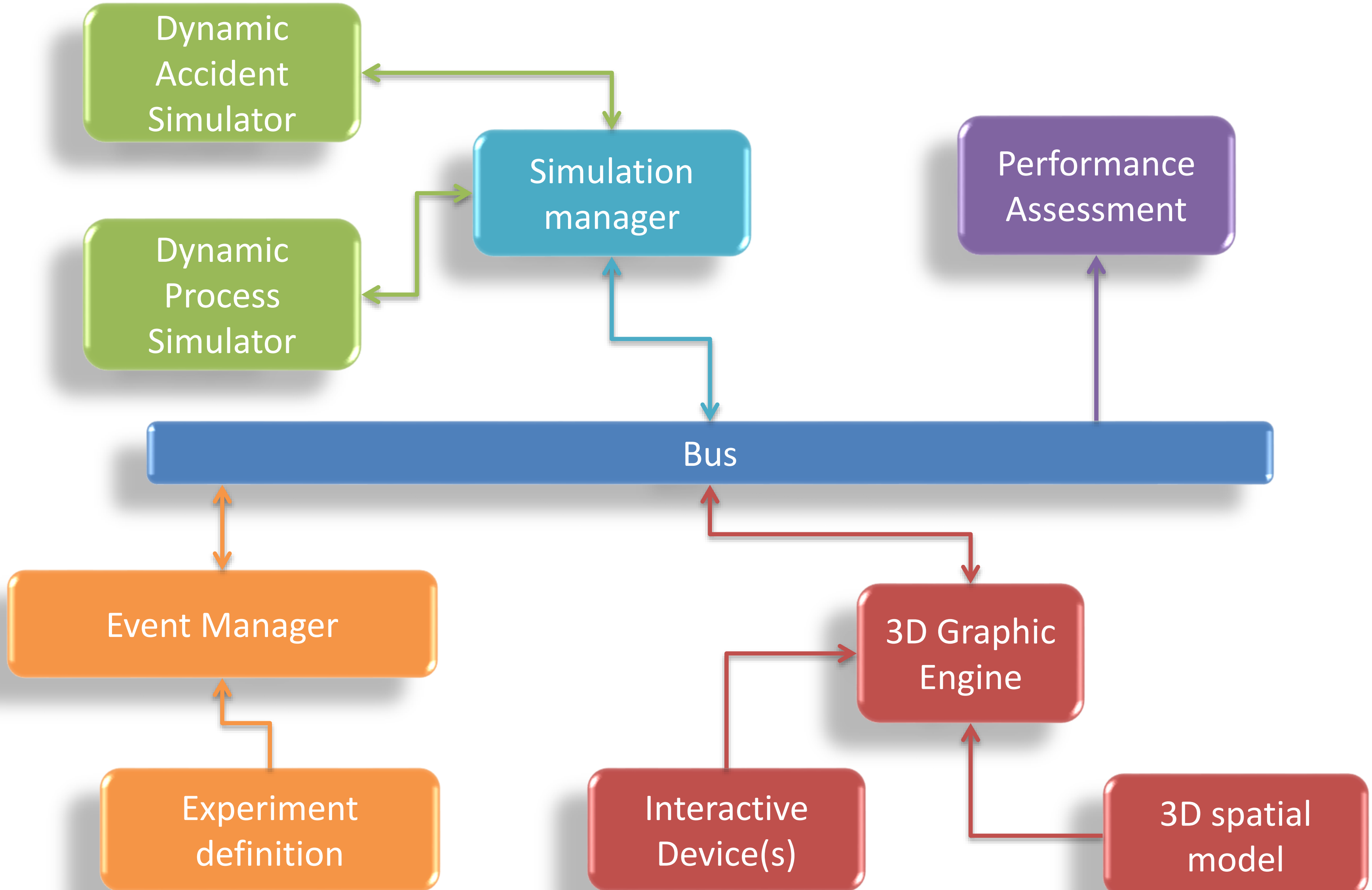
- The **automatic assessment** of industrial operators after a training session is a feature that is recommended and also requested by modern companies.
- The performance assessment is a quite challenging activity that calls for a number of **procedures, metrics, algorithms, methods** many of which are still under development
- The performance assessment of industrial operators cannot be based only on process variables and quantitative data but should focus also on **human factors**
- There is need for a **multidisciplinary approach** where researchers and experts from different cultural backgrounds interact and find a shared synthesis.

# The Architecture

# The architecture



# The architecture



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