Building Management System
Part -2

Actuators…..

An actuator responds to the output signal from a controller and provides the mechanical action to operate the final control device, which is typically a **valve, damper or switch**. A wide range of actuators is available and the chosen actuator must address the following concerns:

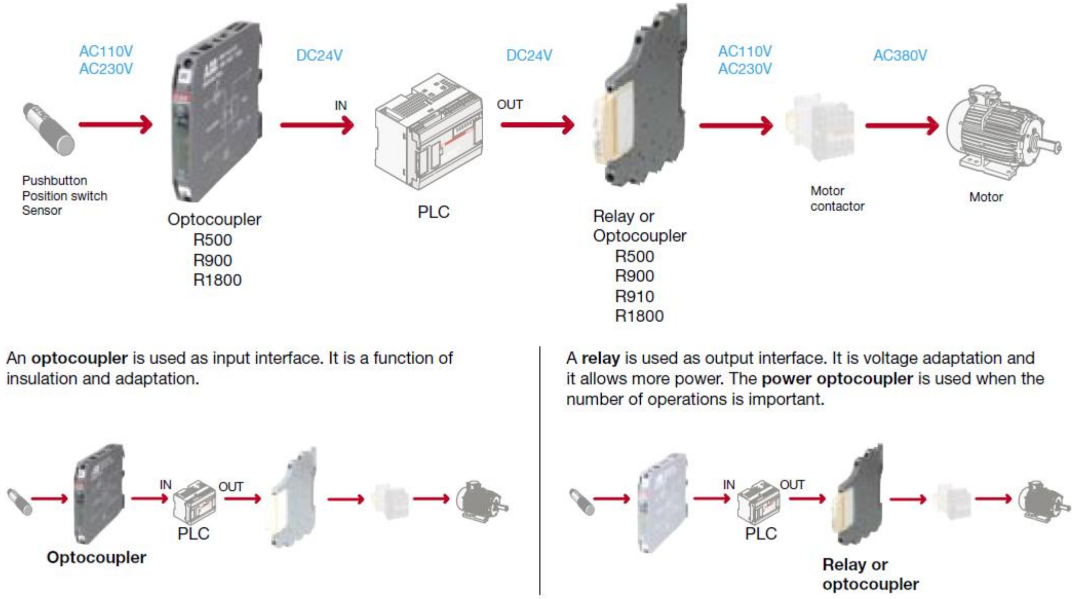
1. Matching the mechanical requirements of the controlled device;
2. Matching the characteristics of the control system, especially the output signal of the controller;
3. Being suitable for its operating environment.

Opto-couplers are used to Separate DDC from Actuators

What is the difference between a Relay and an Optocoupler

- A Relay is an electrical mechanical device used to switch an alternate voltage source. The Relay will use mechanical Isolation between Voltage sources.

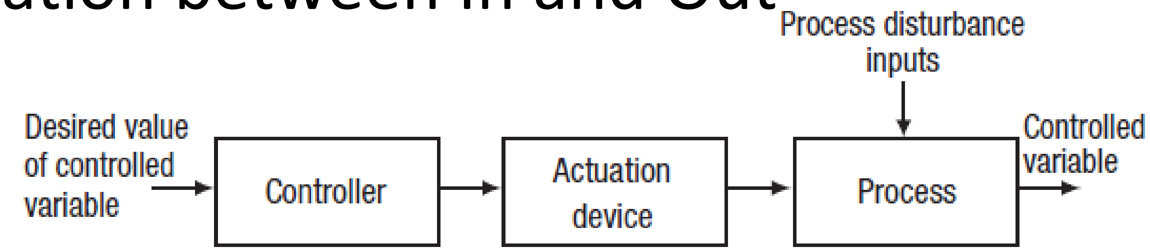
- An Optocoupler is a semiconductor device used to switch an alternate voltage source. The Optocoupler will use Optical(light) Isolation between Voltage sources. Due to the semiconductor properities, the Optocoupler will be use for higher speeds, or more off/on operations (once every 5 minutes)



Controlling

A **control system** is a device, or set of devices, that manages, commands, directs or regulates the behavior of other device(s) or system(s).

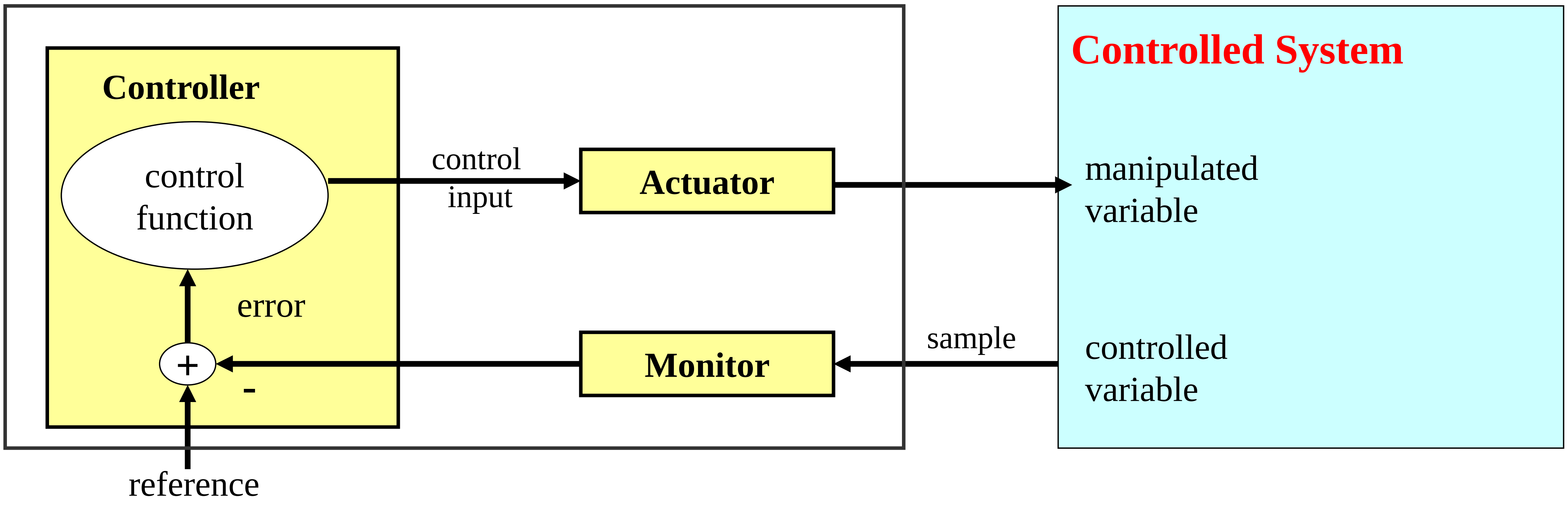
Open Loop – Output Depend on input and also called “non-feedback controller”. Output Based Predicted correlation between In and Out



Closed Loop - Current output is taken into consideration and corrections are made based on feedback. A closed loop system is also called a feedback control system.

- Set – Point or desired value , Control Element, Sensing Element, Control Function-(desired direction, Negative feedback)

Feedback (close-loop) Control



PID Controller

A proportional– integral–derivative controller (PID controller) is a method of the control loop feedback. This method is composing of three controllers

1. Proportional controller (PC)
2. Integral controller (IC)
3. Derivative controller (DC)

$$P = K_P . error(t)$$

$$I = K_I \int_0^t error(t) dt$$

$$D = K_D . \frac{derror(t)}{dt}$$

Parameter	Rise time	Overshoot	Settling time	Steady-state error
K_p	Decrease	Increase	Small change	Decrease
K_i	Decrease	Increase	Increase	Decrease significantly
K_d	Minor decrease	Minor decrease	Minor decrease	No effect in theory

Control Technologies

- Electric
- Pneumatic
- DDC (Direct Digital Control)

Electric Controls

- Can be analog electric or electronic controls
- Use a variable, but continuous, electric voltage or current to operate the control system
- Transmit signals quickly signals and accurately

Advantages

- Can be very accurate and very stable.
- Do not require field calibration, and are drift-free, if good quality sensors are used.
- Relatively easy to implement proportional plus integral (PI) control electronically.

Disadvantages

- Often more expensive than pneumatic controls
- History of reliability problems.
- Difficult to easily interchange parts because of the many different systems.

Pneumatic Controls

- Use compressed air to operate the control system.
- Require the use of very clean, dry and oil-free air.
- Have been used in many HVAC applications

Advantages

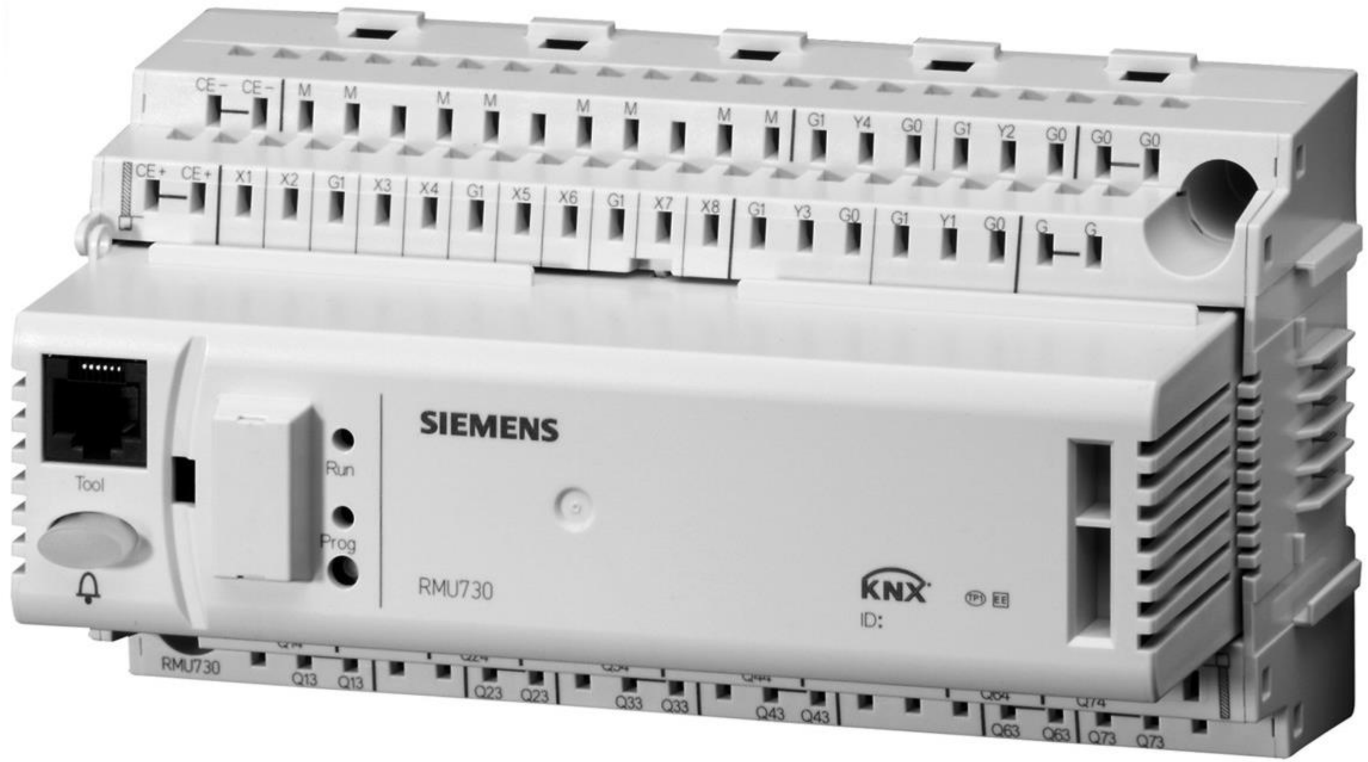
- Are well understood by designers and maintenance people
- Are inherently proportional, inexpensive and very reliable.

Pneumatic Controls

Disadvantages

- Not very precise.
- Required frequent calibration to achieve acceptable accuracy.
- Pneumatic control algorithms are hard to change e.g. changing a P loop to a PI loop.

- Direct Digital Control - DDC



Direct Digital Control is a control process in which a microprocessor controller constantly updates an internal information database by monitoring information from a controlled environment and continuously produces corrective output commands in response to changing control conditions

Direct Digital Controls

- Use electrical pulses to send signals.
- Interface directly with microprocessors and microcomputers (PCs).

Direct Digital Controls

Disadvantages

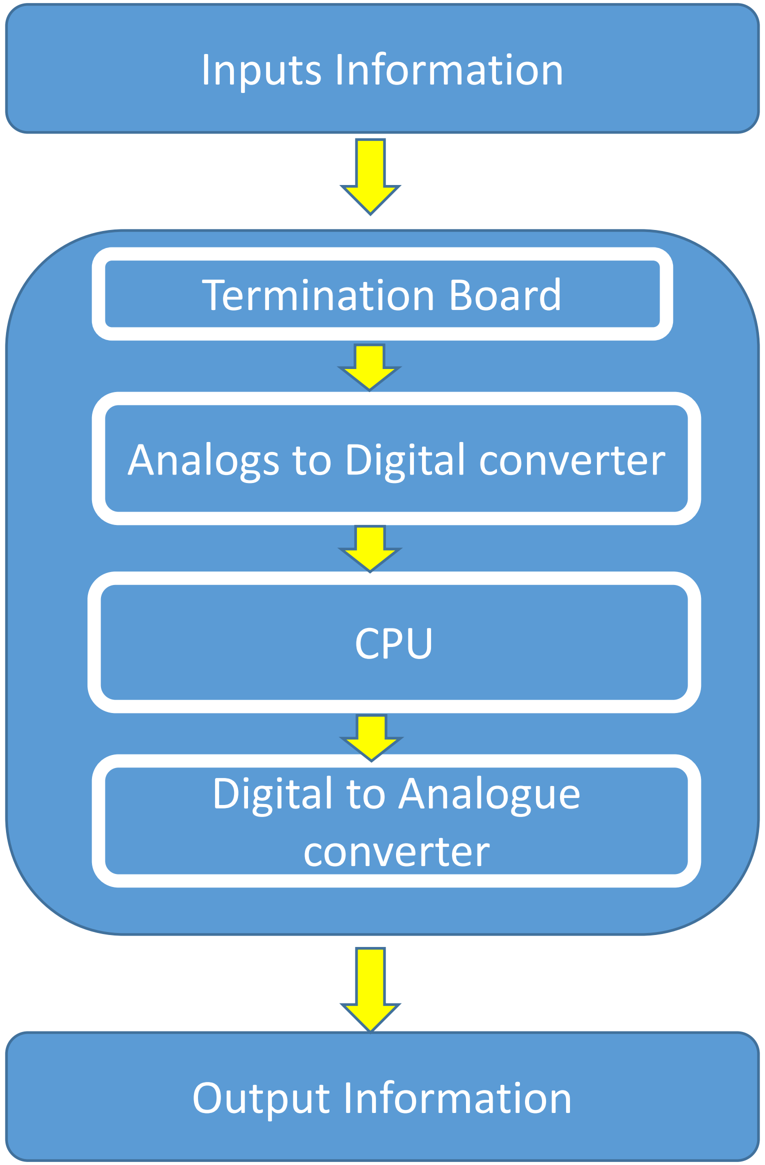
- Not well understood by many maintenance people and facility managers.
- Different programming languages also a problem. BACNET should help this concern.

- BACNET: Building Automation Central Control System Network

Advantages

- Extremely flexible because the control algorithms are implemented in software instead of hardware. Changes are made by keyboard entries, not by adding or modifying hardware elements.
- Very precise; recalibration is not necessary.
- No controller drift.
- Costs have dropped dramatically for DDC components in recent years.
- Analog sensors may still require periodic recalibration, but early reliability problems have been cured.

DDC Controller



CPU

Program
Memory

DDC Vs Conventional Controlling

- Many Control Sequence simultaneously
- Defined Programmed Instructions
- Different Control Strategies/reprogramming can be implemented without changing the hardware
- Accurate and repeatable control of **set-point**
- Accuracy will not drift over time due to lack of maintenance or mechanical fatigues – **Offset** will reduce the performance
- Fine tuning possible
- Adaptive control capabilities (self tuning PID loops, AI-artificial intelligent – Neural networks, nonlinear expert control methods

DDC Controller

- **Local Software**
- **Types of DDC controllers**
  - Fixed function
  - Configurable
  - Text programmable
  - Graphic programmable
- **Point Definition**
  - Ranging (linear, calculated, polynomial)
  - Filtering (smoothing and debounce)
- **Interlocks**

- **Communication options between DDC Controller and Supervisory Controller include proprietary, LonWorks and BACnet**
- **LonWorks is an open standard promoted by Echelon Corporation**
- **BACnet is an open standard promoted by ASHRAE**

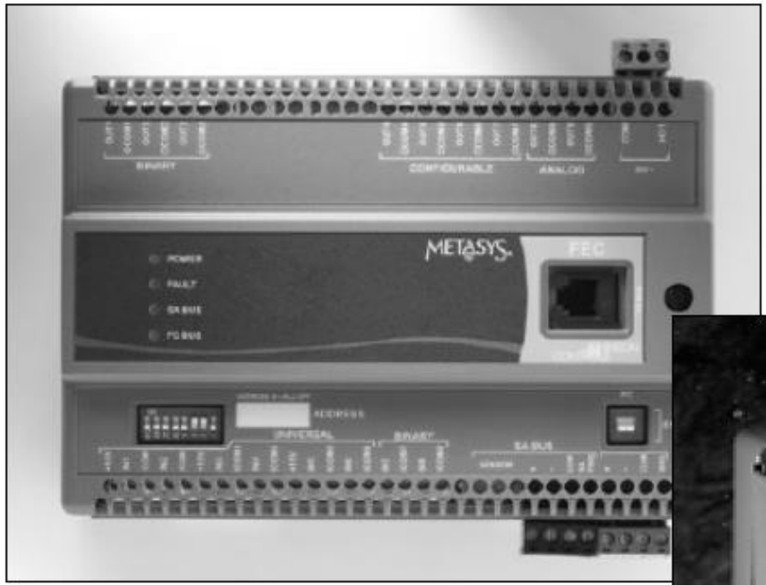
- **Control Loops**
- Proportional plus integral control commonly used

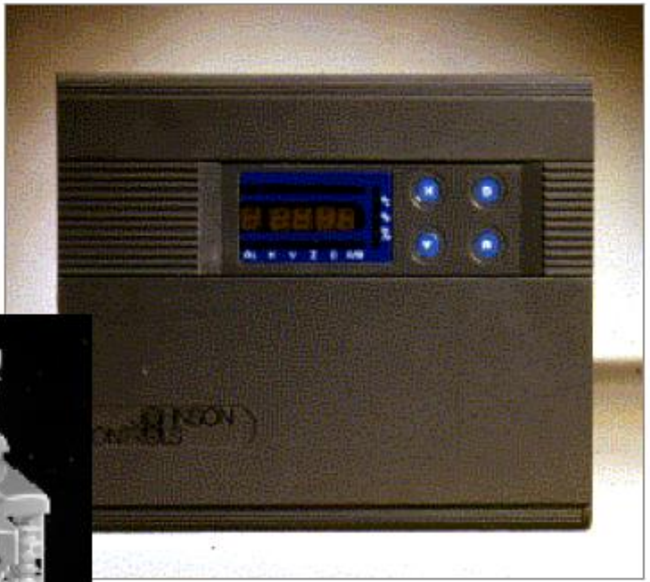
- **Other software routines used in local control logic**
- Minimum, maximum, average, calculator, etc.
- Psychometric calculations
- Timing (delays, pulses, etc.)
- Boolean and comparator operators
- Time clock and backup schedules

Types of DDCs

- Compact & Modular
  - o Compact – fixed numbers of I/O per controller
  - o Modular - expandable
- Based on Protocols
  - BACnet/MSTP,
  - BACnet/IP
  - Lon
  - MODbus
  - Ect…

DDC Controller





Compact – fixed numbers of I/O per controller

Compact – fixed numbers of I/O per controller

AO-1
AI-4
DI-4
DO-2

AO-2
AI-6
DI-14
DO-6

AO-4
AI-6
DI-14
DO-8

Modular - expandable

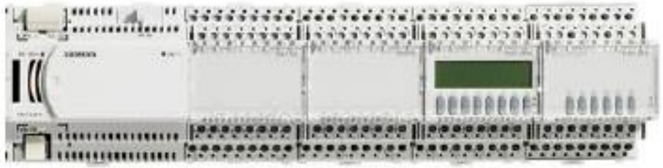


Figure 2. TX-I/O Power Supply and TX-I/O Modules.

Figure 3. PXC Modular, TX-I/O Power Supply, and TX-I/O Modules.

Direct Digital Controllers Input/ Outputs

Digital Inputs Examples:-

Differential Pressure Switch is an example of Digital Input. Usually installed across a fan or a filter. If the contact is closed the DDC can detect either the fan is running or the filter is clogged.

Smoke Detector installed in the duct to allow the controller to stop the Air Handling Unit in case of Fire.

Auxiliary contact from contactor to indicate if the contactor is energized or NOT.

Direct Digital Controllers Input/ Outputs

Analog Inputs Example:-

Temperature Sensors/ Setpoint Modules for Rooms.
Temperature Sensors for Ducts.
Immersion temperature Sensors for water Pipes.



Humidity Transmitters for Rooms and Ducts.


Differential Pressure Transmitters for Clean Rooms.

Direct Digital Controllers Input/ Outputs

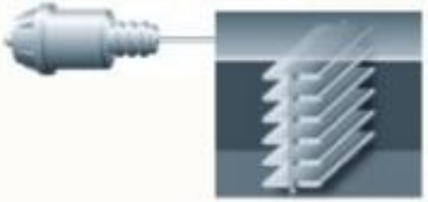
Analog Output Examples:-

DDC produce a voltage signal ranged from 0 to 10 Volt. According to the value the controlled device respond.

To Control the Fan Speed via inverter (Speed Drive).

To Modulate water Valve .

To Modulate Damper Motor and control Air Flow.



Direct Digital Controllers Input/ Outputs

Digital Output Examples:-

Digital output is a relay output controlled by DDC

To Energize contactor in the motor control center in order to start Fan or Pump.

To Start a condensing unit when using DX Air Handling Units.

To energize Heater Battery Stages via contactors

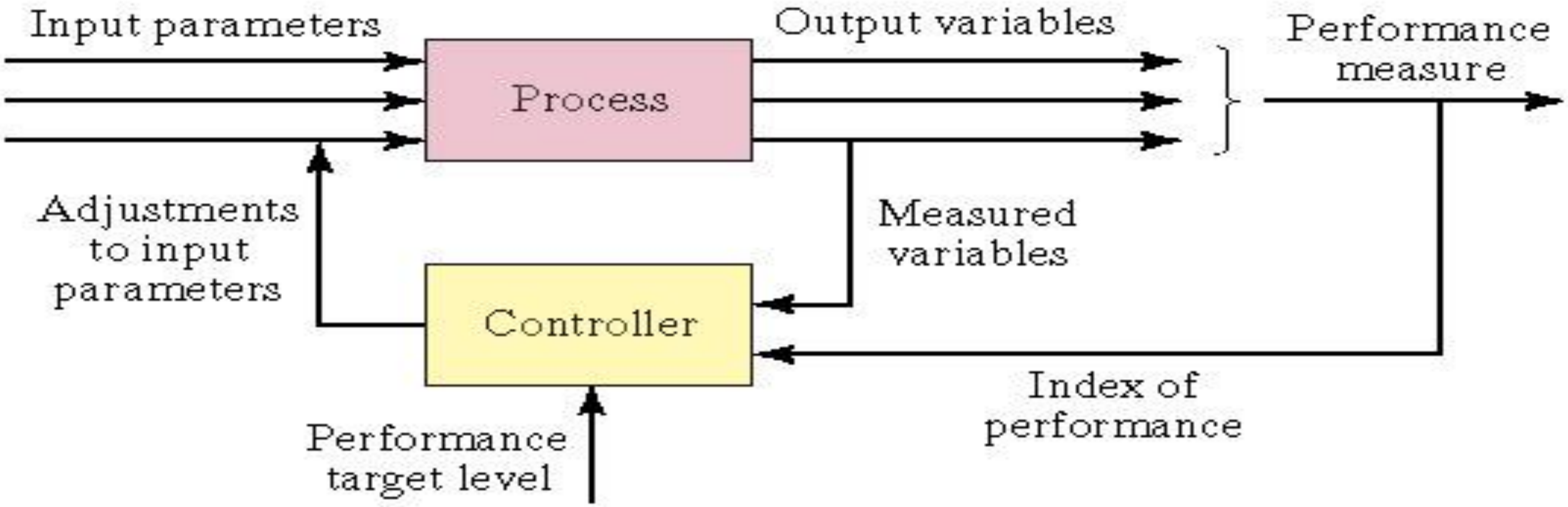
Types of Continuous Process Control

- Regulatory control
- Feedforward control
- Steady-State optimization
- Adaptive control
- On-line search strategies
- Other specialized techniques
    - Expert systems
    - Neural networks

Regulatory Control

- Objective - maintain process performance at a certain level or within a given tolerance band of that level
  - Appropriate when performance relates to a quality measure
- Performance measure is sometimes computed based on several output variables
  - Performance measure is called the *Index of performance* (IP)
- Problem with regulatory control is that an error must exist in order to initiate control action

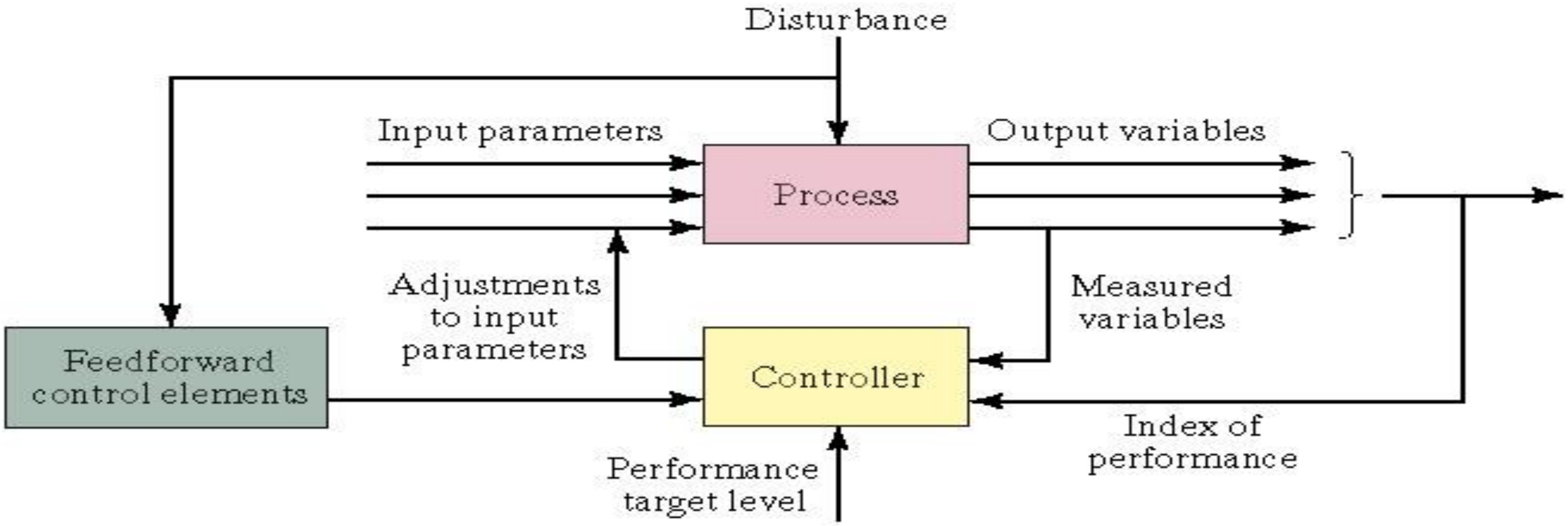
Regulatory Control



Feedforward Control

- Objective - anticipate the effect of disturbances that will upset the process by sensing and compensating for them before they affect the process
- Mathematical model captures the effect of the disturbance on the process
- Complete compensation for the disturbance is difficult due to variations, imperfections in the mathematical model and imperfections in the control actions
  - Usually combined with regulatory control
- Regulatory control and feedforward control are more closely associated with process industries

Feedforward Control
Combined with Feedback Control



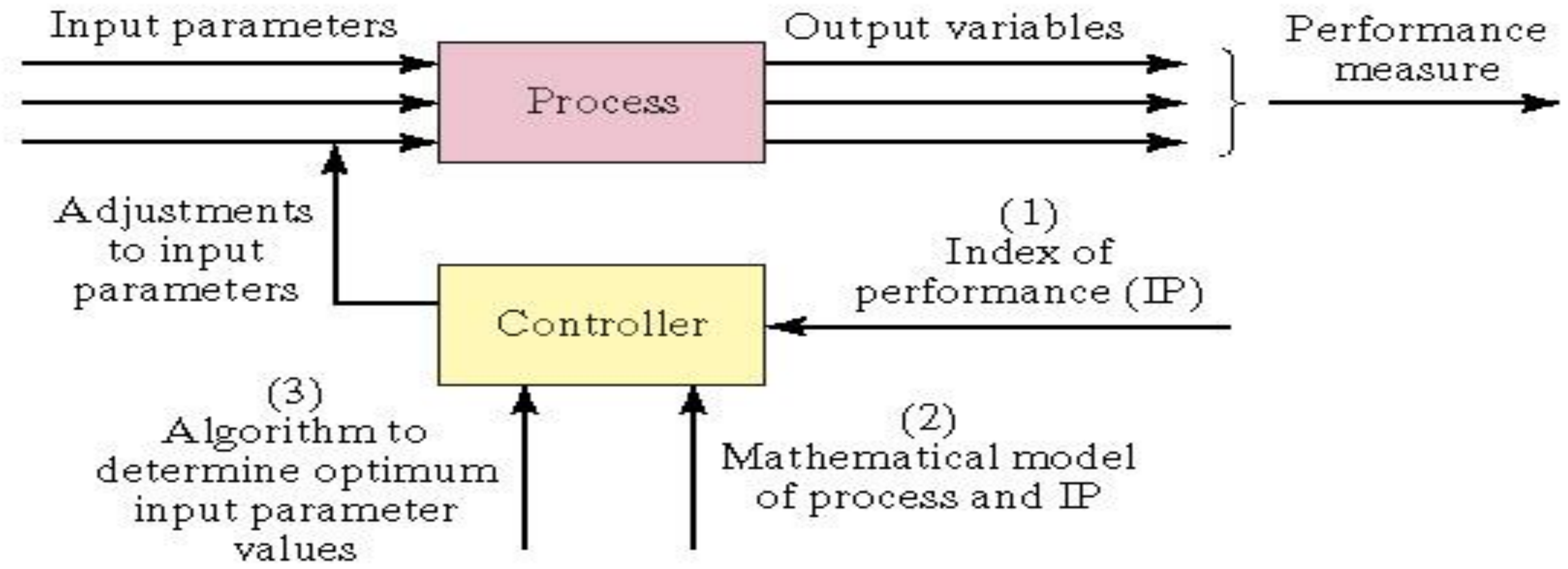
Steady-State Optimization

Class of optimization techniques in which the process exhibits the following characteristics:

1. Well-defined index of performance (IP)
2. Known relationship between process variables and IP
3. System parameter values that optimize IP can be determined mathematically

- Open-loop system
- Optimization techniques include differential calculus, mathematical programming, etc.

Steady State (Open-Loop) Optimal Control



Adaptive Control

- Because steady-state optimization is open-loop, it cannot compensate for disturbances
- Adaptive control is a self-correcting form of optimal control that includes feedback control
  - Measures the relevant process variables during operation (feedback control)
  - Uses a control algorithm that attempts to optimize some index of performance (optimal control)

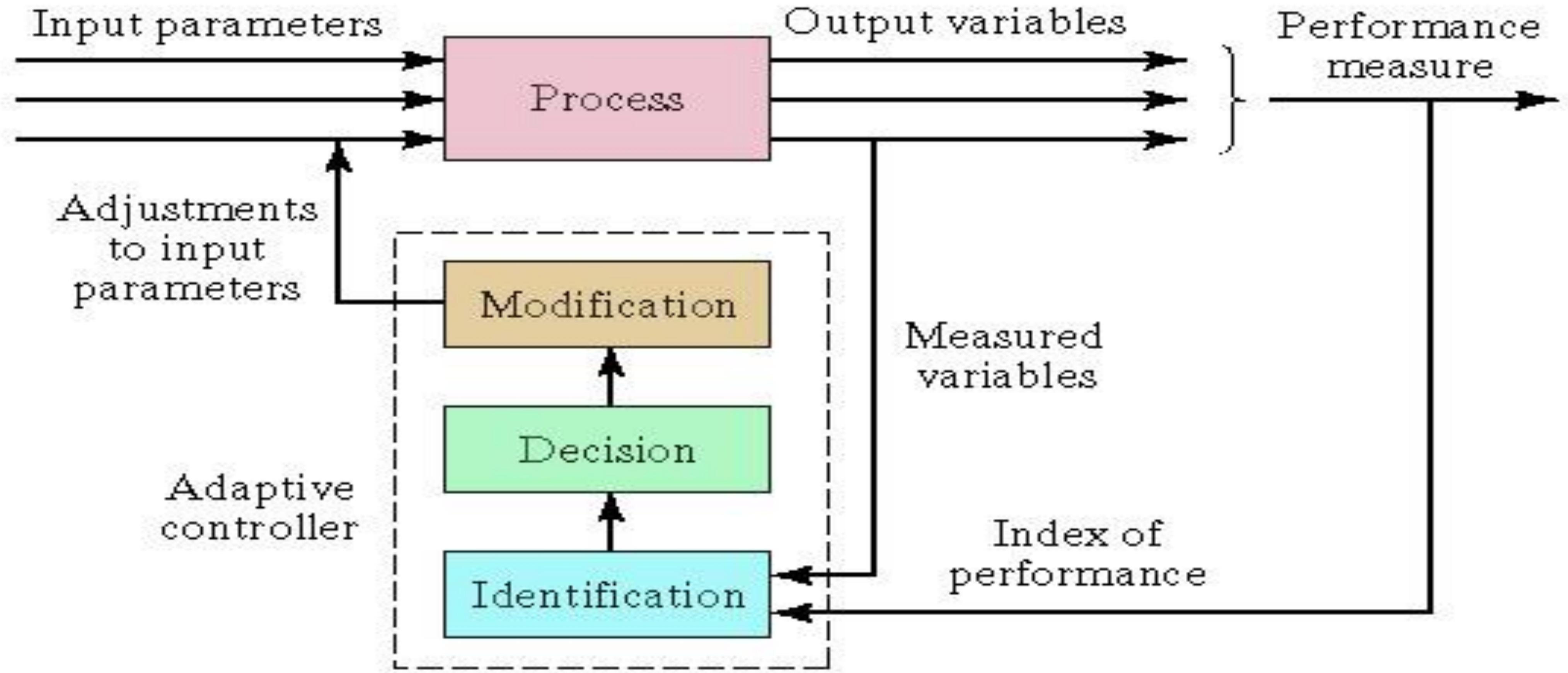
Adaptive Control Operates in a Time-Varying Environment

- The environment changes over time and the changes have a potential effect on system performance
  - Example: Supersonic aircraft operates differently in subsonic flight than in supersonic flight
- If the control algorithm is fixed, the system may perform quite differently in one environment than in another
- An adaptive control system is designed to compensate for its changing environment by altering some aspect of its control algorithm to achieve optimal performance

Three Functions in Adaptive Control

1. Identification function – current value of IP is determined based on measurements of process variables
2. Decision function – decide what changes should be made to improve system performance
    - Change one or more input parameters
    - Alter some internal function of the controller
3. Modification function – implement the decision function
    - Concerned with physical changes (hardware rather than software)

Adaptive Control System



On-Line Search Strategies

- Special class of adaptive control in which the decision function cannot be sufficiently defined
  - Relationship between input parameters and IP is not known, or not known well enough to implement the previous form of adaptive control
- Instead, experiments are performed on the process
  - Small systematic changes are made in input parameters to observe effects
- Based on observed effects, larger changes are made to drive the system toward optimal performance

Discrete Control Systems

- Process parameters and variables are discrete
- Process parameters and variables are changed at discrete moments in time
- The changes are defined in advance by the program of instructions
- The changes are executed for either of two reasons:
  1. The state of the system has changed (event-driven changes)
  2. A certain amount of time has elapsed (time driven changes)

Event-Driven Changes

- Executed by the controller in response to some event that has altered the state of the system
- Examples:
  - A robot loads a workpart into a fixture, and the part is sensed by a limit switch in the fixture
  - The diminishing level of plastic in the hopper of an injection molding machine triggers a low-level switch, which opens a valve to start the flow of more plastic into the hopper
  - Counting parts moving along a conveyor past an optical sensor

Time-Driven Events

- Executed by the controller either at a specific point in time or after a certain time lapse
- Examples:
  - The factory "shop clock" sounds a bell at specific times to indicate start of shift, break start and stop times, and end of shift
  - Heat treating operations must be carried out for a certain length of time
  - In a washing machine, the agitation cycle is set to operate for a certain length of time
    - By contrast, filling the tub is event-driven

Two Types of Discrete Control

1. Combinational logic control – controls the execution of event-driven changes
   - Also known as logic control
   - Output at any moment depends on the values of the inputs
   - Parameters and variables = 0 or 1 (OFF or ON)
2. Sequential control – controls the execution of time-driven changes
   - Uses internal timing devices to determine when to initiate changes in output variables

Computer Process Control

- Origins in the 1950s in the process industries
  - Mainframe computers – slow, expensive, unreliable
  - Set point control
  - Direct digital control (DDC) system installed 1962
- Minicomputer introduced in late 1960s, microcomputer introduced in early 1970s
- Programmable logic controllers introduced early 1970s for discrete process control
- Distributed control starting around 1975
- PCs for process control early 1990s

Two Basic Requirements for Real-Time Process Control

1. Process-initiated interrupts
   - Controller must respond to incoming signals from the process (event-driven changes)
   - Depending on relative priority, controller may have to interrupt current program to respond
2. Timer-initiated actions
   - Controller must be able to execute certain actions at specified points in time (time-driven changes)
   - Examples: (1) scanning sensor values, (2) turning switches on and off, (3) re-computing optimal parameter values

Other Computer Control Requirements

3. Computer commands to process
   - To drive process actuators
4. System- and program-initiated events
   - System initiated events - communications between computer and peripherals
   - Program initiated events - non-process-related actions, such as printing reports
5. Operator-initiated events – to accept input from personnel
   - Example: emergency stop

Capabilities of Computer Control

- Polling (data sampling)
- Interlocks
- Interrupt system
- Exception handling

Polling (Data Sampling)

Periodic sampling of data to indicate status of process

- Issues:
  1. Polling frequency – reciprocal of time interval between data samples
  2. Polling order – sequence in which data collection points are sampled
  3. Polling format – alternative sampling procedures:
     - All sensors polled every cycle
     - Update only data that has changed this cycle
     - High-level and low-level scanning

Interlocks

Safeguard mechanisms for coordinating the activities of two or more devices and preventing one device from interfering with the other(s)

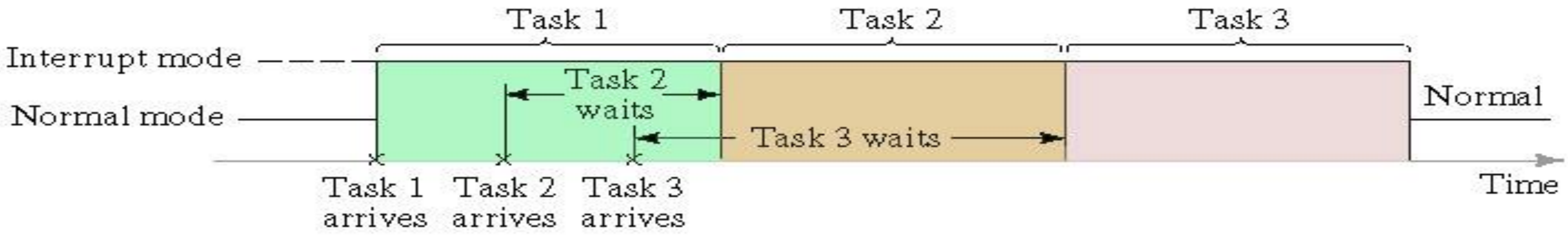
1. Input interlocks – signal from an external device sent to the controller; possible functions:
    - Proceed to execute work cycle program
    - Interrupt execution of work cycle program
2. Output interlocks – signal sent from controller to external device

Interrupt System

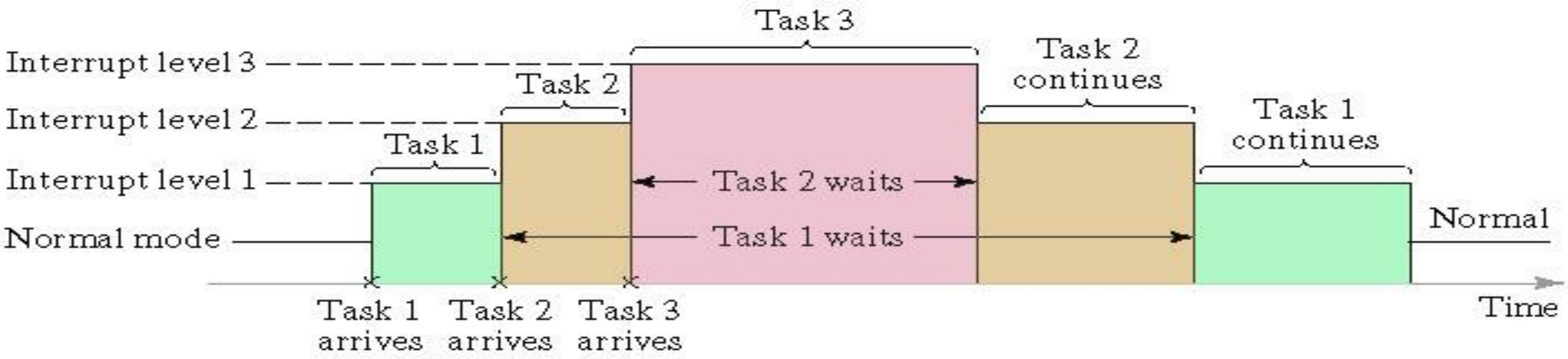
Computer control feature that permits the execution of the current program to be suspended in order to execute another program in response to an incoming signal indicating a higher priority event

- Internal interrupt – generated by the computer itself
  - Examples: timer-initiated events, polling, system- and program initiated interrupts
- External interrupts – generated external to the computer
  - Examples: process-initiated interrupts, operator inputs

Interrupt Systems:
(a) Single-Level and (b) Multilevel



(a)



(b)

Exception Handling

An exception is an event that is outside the normal or desired operation of the process control system

- Examples of exceptions:
  - Product quality problem
  - Process variable outside normal operating range
  - Shortage of raw materials
  - Hazardous conditions, e.g., fire
  - Controller malfunction
- Exception handling is a form of error detection and recovery

Forms of Computer Process Control

1. Computer process monitoring
2. Direct digital control (DDC)
3. Numerical control and robotics
4. Programmable logic control
5. Supervisory control
6. Distributed control systems and personal computers

Computer Process Monitoring

Computer observes process and associated equipment, collects and records data from the operation

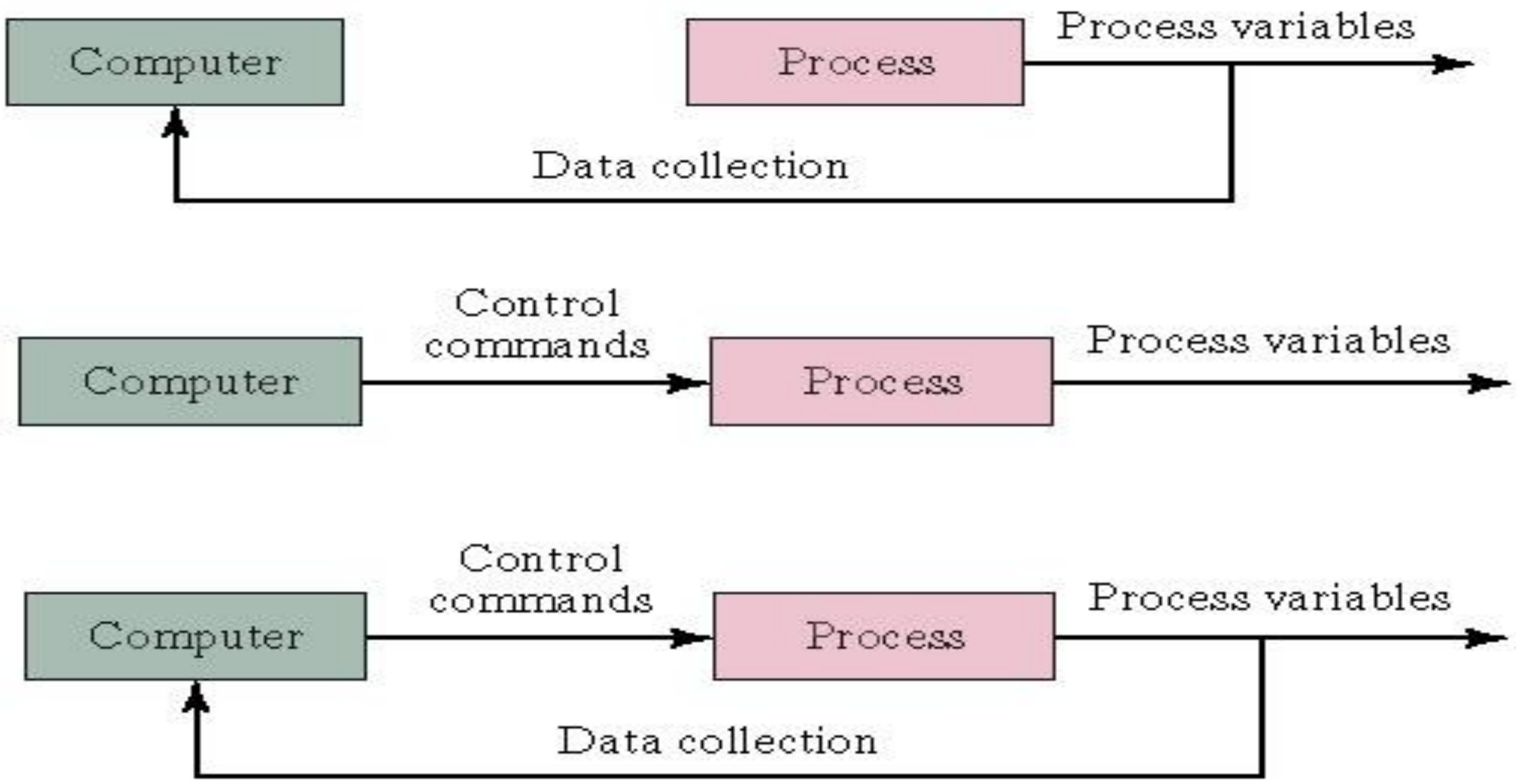
- The computer does not directly control the process
- Types of data collected:
  - Process data – input parameters and output variables
  - Equipment data – machine utilization, tool change scheduling, diagnosis of malfunctions
  - Product data – to satisfy government requirements, e.g., pharmaceutical and medical

(a) Process Monitoring, (b) Open-Loop Control, and (c) Closed-Loop Control

(a)

(b)

(c)

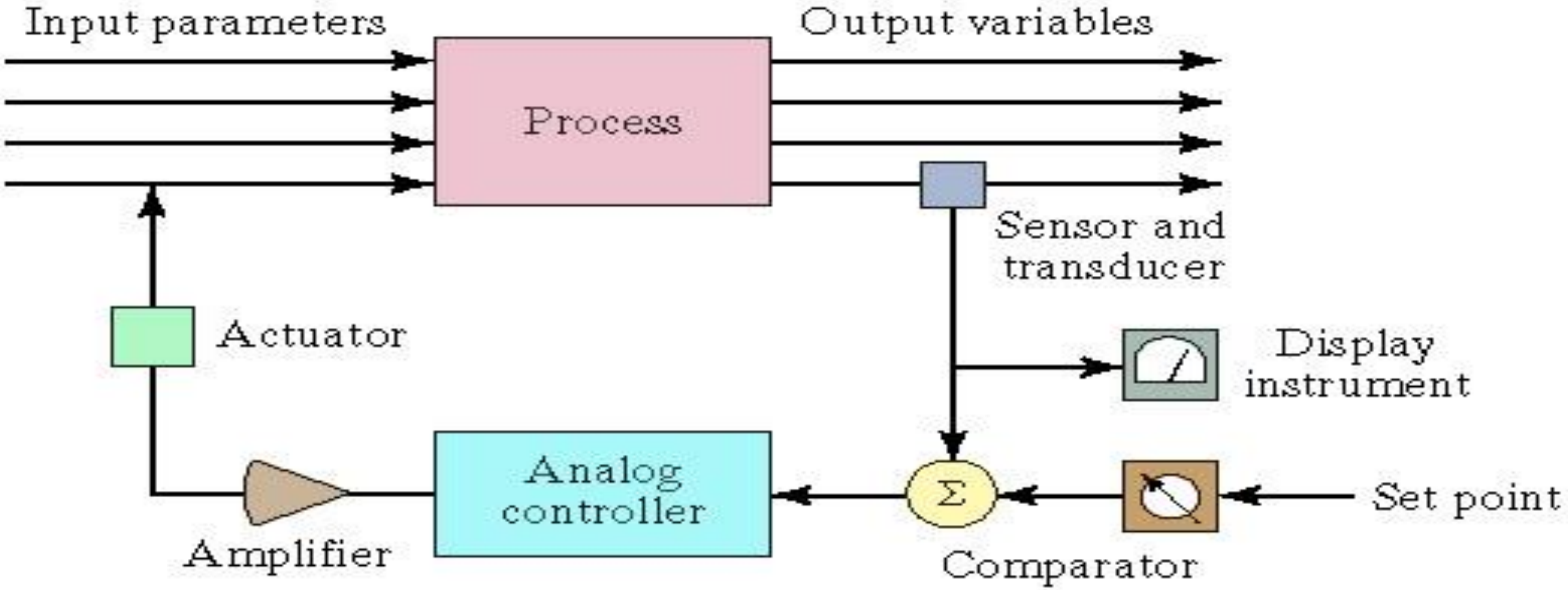


Direct Digital Control (DDC)

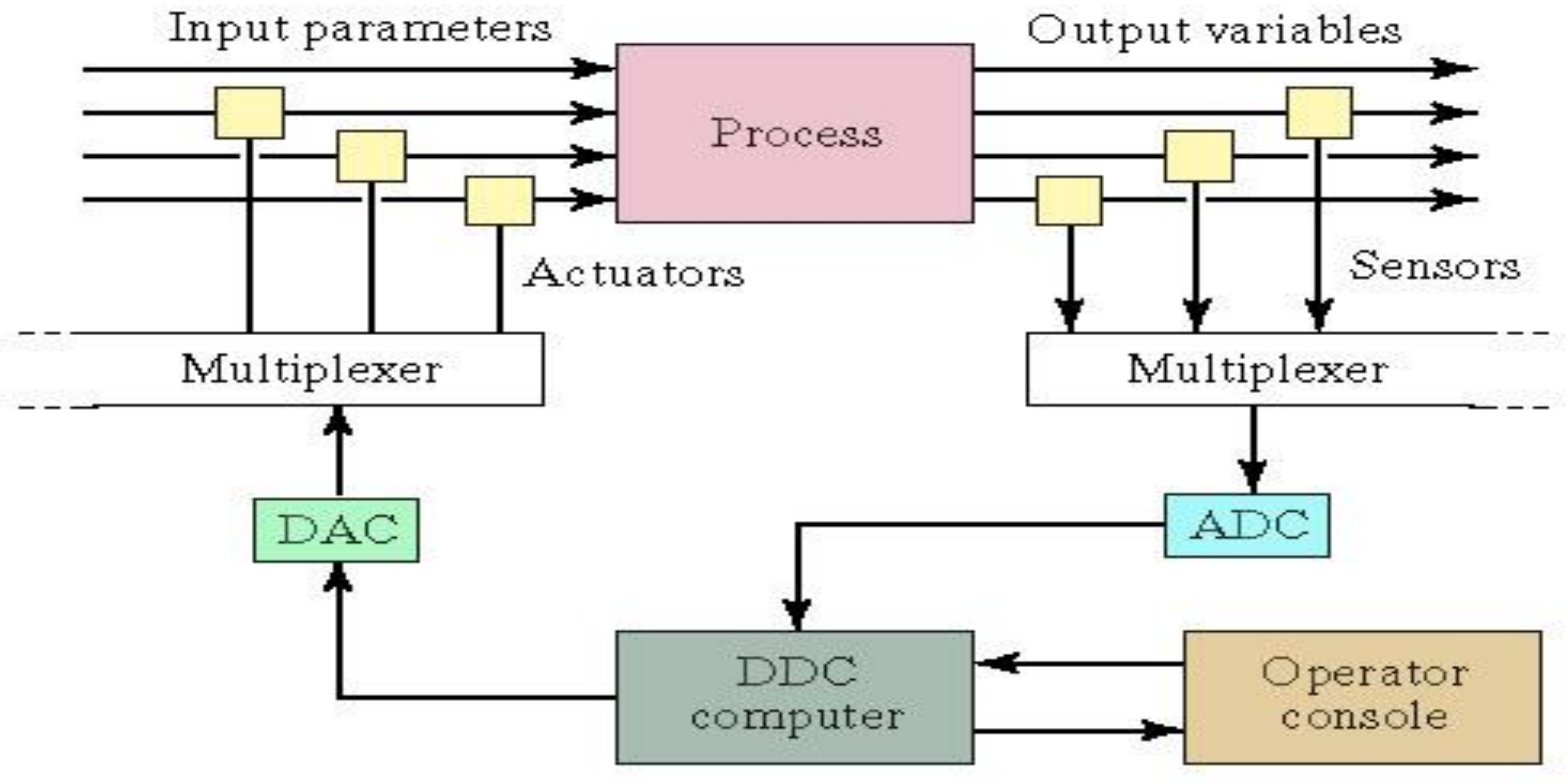
Form of computer process control in which certain components in a conventional analog control system are replaced by the digital computer

- Circa: 1960s using mainframes
- Applications: process industries
- Accomplished on a time-shared, sampled-data basis rather than continuously by dedicated components
  - Components remaining in DDC: sensors and actuators
  - Components replaced in DDC: analog controllers, recording and display instruments, set point dials

A Typical Analog Control Loop



Components of a Direct Digital Control System



DDC (continued)

- Originally seen as a more efficient means of performing the same functions as analog control
- Additional opportunities became apparent in DDC:
  - More control options than traditional analog control (PID control), e.g., combining discrete and continuous control
  - Integration and optimization of multiple loops
  - Editing of control programs

Numerical Control and Robotics

- Computer numerical control (CNC) – computer directs a machine tool through a sequence of processing steps defined by a program of instructions
  - Distinctive feature of NC – control of the position of a tool relative to the object being processed
  - Computations required to determine tool trajectory
- Industrial robotics – manipulator joints are controlled to move and orient end-of-arm through a sequence of positions in the work cycle

Programmable Logic Controller (PLC)

Microprocessor-based controller that executes a program of instructions to implement logic, sequencing, counting, and arithmetic functions to control industrial machines and processes

- Introduced around 1970 to replace electromechanical relay controllers in discrete product manufacturing
- Today's PLCs perform both discrete and continuous control in both process industries and discrete product industries

Supervisory Control

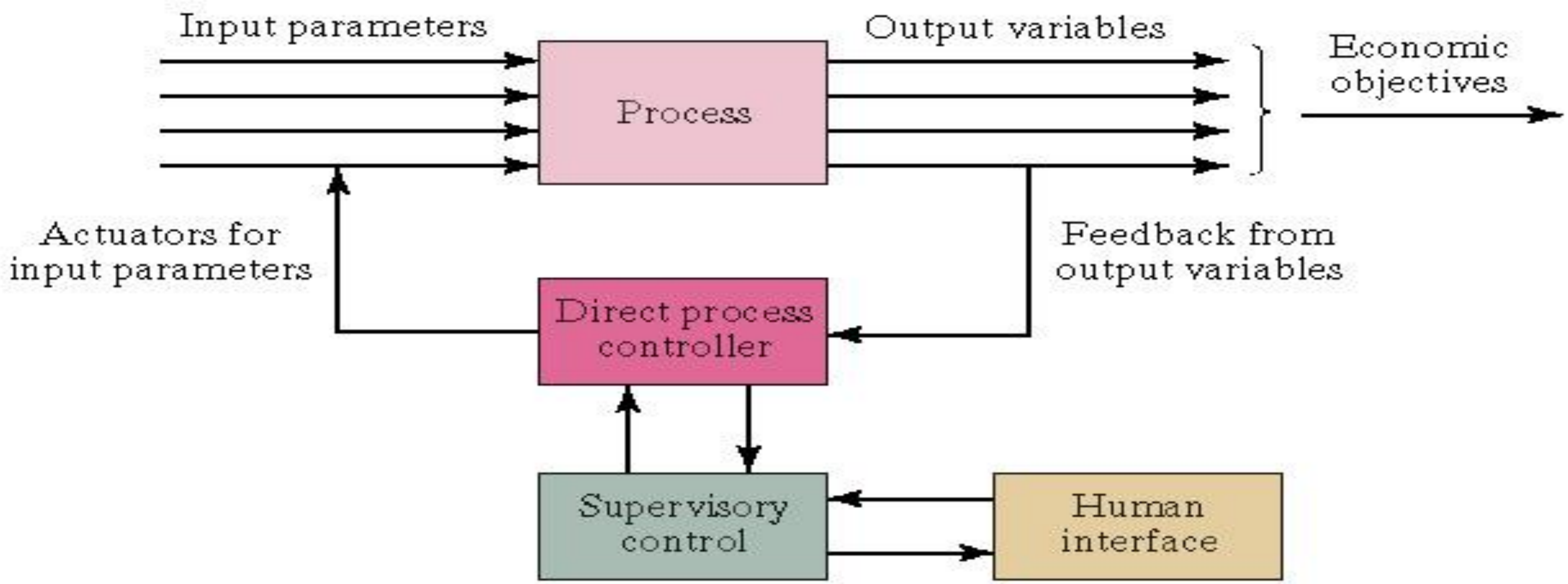
In the process industries, supervisory control denotes a control system that manages the activities of a number of integrated unit operations to achieve certain economic objectives

In discrete manufacturing, supervisory control is the control system that directs and coordinates the activities of several interacting pieces of equipment in a manufacturing system

- Functions: efficient scheduling of production, tracking tool lives, optimize operating parameters

- Most closely associated with the process industries

Supervisory Control Superimposed on Process Level Control System

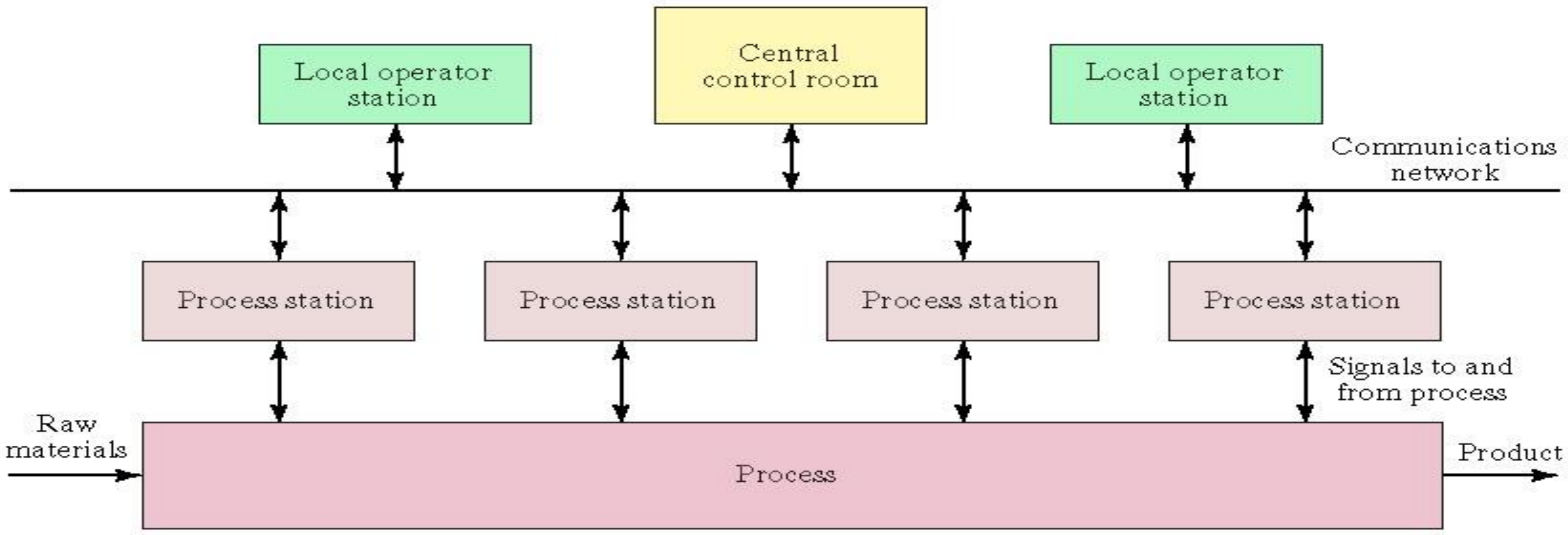


Distributed Control Systems (DCS)

Multiple microcomputers connected together to share and distribute the process control workload

- Features:
  - Multiple process control stations to control individual loops and devices
  - Central control room where supervisory control is accomplished
  - Local operator stations for redundancy
  - Communications network (data highway)

Distributed Control System



DCS Advantages

- Can be installed in a very basic configuration, then expanded and enhanced as needed in the future
- Multiple computers facilitate parallel multitasking
- Redundancy due to multiple computers
- Control cabling is reduced compared to central controller configuration
- Networking provides process information throughout the enterprise for more efficient plant and process management

PCs in Process Control

Two categories of personal computer applications in process control:

1. Operator interface – PC is interfaced to one or more PLCs or other devices that directly control the process
   - PC performs certain monitoring and supervisory functions, but does not directly control process
2. Direct control – PC is interfaced directly to the process and controls its operations in real time
   - Traditional thinking is that this is risky

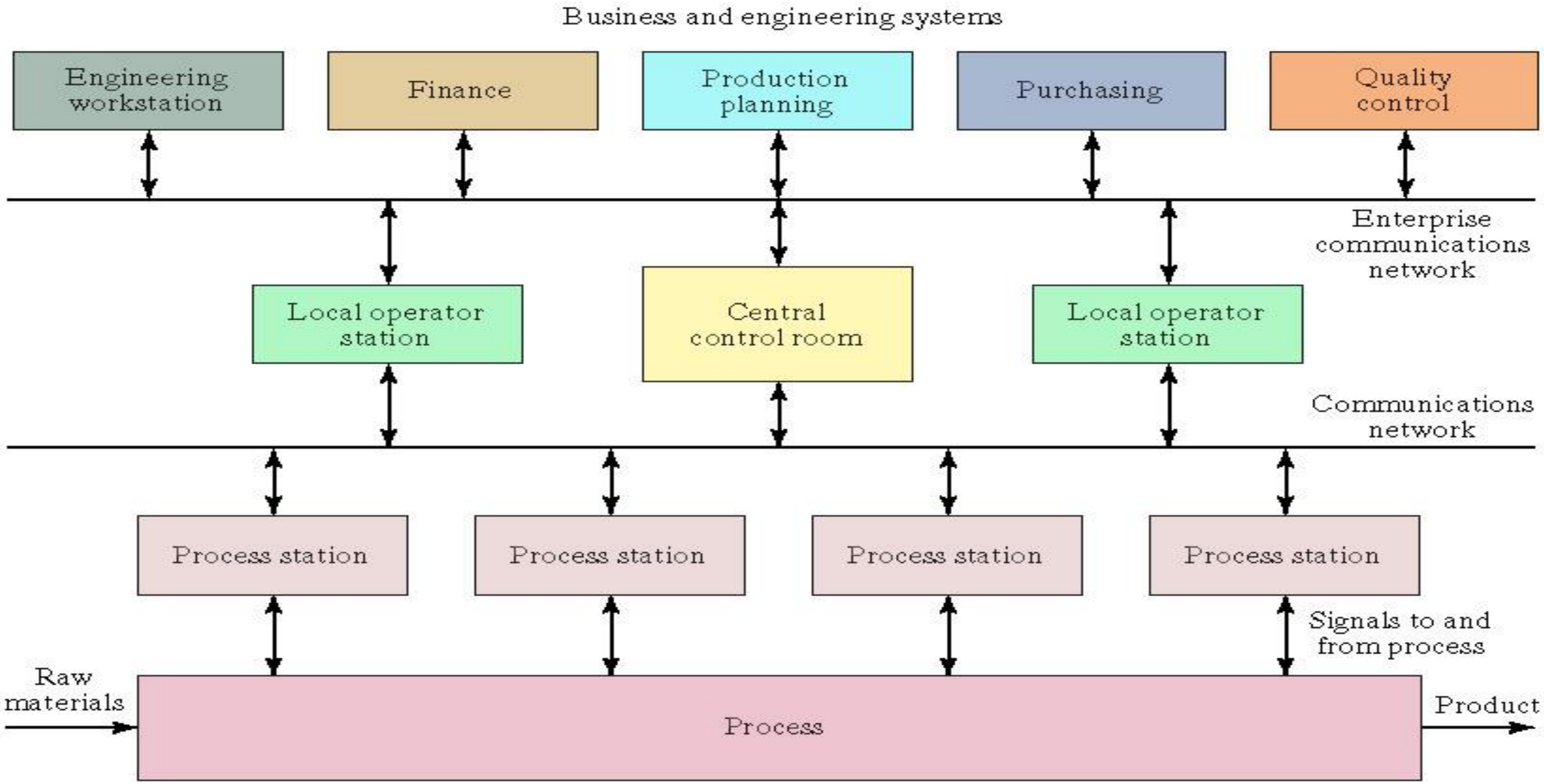
Enablers of PCs for Direct Control

- Widespread familiarity of workers with PCs
- Availability of high performance PCs
  - Cycle speeds of PCs now exceed those of PLCs
- Open architecture philosophy in control system design
  - Hardware and software vendors comply with standards that allow their products to be interoperable
- PC operating systems that facilitate real-time control and networking
- PC industrial grade enclosures

Enterprise-Wide Integration of Factory Data

- Managers have direct access to factory operations
- Planners have most current data on production times and rates for scheduling purposes
- Sales personnel can provide realistic delivery dates to customers, based on current shop loading
- Order trackers can provide current status information to inquiring customers
- QC can access quality issues from previous orders
- Accounting has most recent production cost data
- Production personnel can access product design data to clarify ambiguities

Enterprise-Wide PC-based Distributed Control System



Assignment-1
Categorize the following control signals as AI, AO, DI , DO

- Temperature
- Light level is above the set value
- Humidity level
- Pressure
- System Auto/Manul Status
- Pressure cut OFF Switch ON
- Door open Closed
- Fan Speed (rpm)
- CO2 level in ppm
- Water level reached to High level
- Return Duct Air Speed
- Fire Alarm system alarming
- Tank is empty
- AHU filter is clogged
- Fan ON/OFF command
- Valve modulating signal
- Differential Pressure Signal
- Main Breaker Trip Alarm Status
- Valve position feed back signal
- Damper Regulation
- ON/OFF damper control
- Boiler Flue Gas Temperature
- CO level of the car park
- Fan ON/OFF Status
- Unit faulty Alarm condition
- Outdoor Humidity Level
- Light Level
- Diesel Tank Level
- Water leakage
- Duct smoke detection
- Transformer High Temp relay operation
- Drainage water tank high level
- Lift Going up

Write down key features of a selected DDC Controller

- Clock Speed
- Bit rate
- A/D Resolution (analog in)
- Operating voltage
- Rated voltage
- Operating frequency
- Power Consumption
- Internal fuse Rate
- Processor
- Memory
- Scan cycle Max. 1 s
- Data backup in case of power failure
- Battery Backup of SDRAM
- Battery Backup of Realtime Clock

Software for BMS

Protocols

- Set of codes, message structure, procedures in terms of hardware and software which permits communication is referred as communication protocols.
- ISO (International Standard for Standardization) introduce OSI (Open System Interconnection)
- 7 layers Architecture

Application layer

- The application layer is the OSI layer closest to the end user, which means that both the OSI application layer and the user interact directly with the software application.
  - Some examples of application layer implementations include Telnet, File Transfer Protocol (FTP), and Simple Mail Transfer Protocol (SMTP), DNS, Web/Http.

Presentation layer

- The presentation layer provides a variety of coding and conversion functions that are applied to application layer data. These functions ensure that information sent from the application layer of one system would be readable by the application layer of another system. Some examples of presentation layer coding and conversion schemes include common data representation formats, conversion of character representation formats, common data compression schemes, and common data encryption schemes.
- AFP, AppleShare File Protocol , GIF, GIF , ICA Citrix Systems Core Protocol, JPEG, Joint Photographic Experts Group , LPP, Lightweight Presentation Protocol ,NCP, NetWare Core Protocol

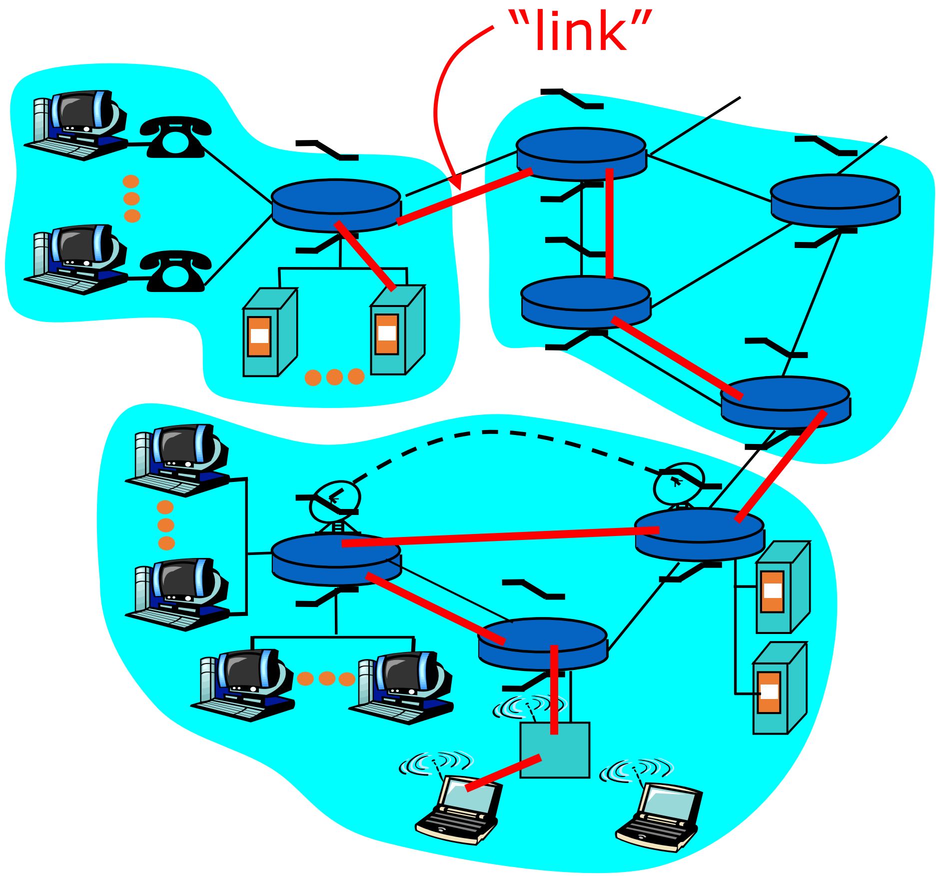
Session layer

- The session protocol allows session-service users (SS-users) to communicate with the session service.

The OSI protocol suite implements two types of services at the transport layer: connection-oriented transport service and connectionless transport service.

The network layer provides the functional and procedural means of transferring variable length data sequences from a source to a destination via one or more networks while maintaining the quality of service requested by the transport layer

The data link layer provides reliable transit of data across a physical network link. Different data link layer specifications define different network and protocol characteristics, including physical addressing, network topology, error notification, sequencing of frames, and flow control.


"link"

The physical layer defines the electrical, mechanical, procedural, and functional specifications for activating, maintaining, and deactivating the physical link between communicating network systems. Physical layer specifications define characteristics such as voltage levels, timing of voltage changes, physical data rates, maximum transmission distances, and physical connectors.

Physical layer implementations can be categorized as either LAN or WAN specifications

Network Protocols

- Predefined set of rules and conventions in order to maintain error free and optimal convenient when transferring information within the network
- It defines
  - Connectors
  - Cables
  - Signals
  - Data formats
  - Error checking
  - Algorithams

Why We need communication in BMS

- Share " Outdoor temperature" @ Controller level
- To see every thing in the central BMS PC

Physical Layer

- Cables losess
  - I^2R losses
  - Signal Distortion – Capacitance (RC - Problem with higher frequencies)
  - Reflection due to impedance mismatching
  - External noises and disturbances
- Factors influencing electrical characteristics of Cables
  - Geometry
  - Constituent metallic
  - Insulation
- Few parameters of cables
  - Twisted Pairs – DDC (20 ~ 22 AWG)
  - Shield – sheath of Braided copper, Aluminum foil or both
  - Drain wire – electrically connect shield to the termination, and grounded at the single point
  - Solid or multi-stranded
  - Plenum cables – cables above the ceiling

$$C_L = \frac{2\pi\varepsilon_0\varepsilon_r}{\ln\left(\frac{D}{d}\right)}$$

where,

C_L = capacitance per unit length
ε_r = relative dielectric constant of the medium.
ε_0 = permittivity of free space or 0.225 pF/inch
d = inner radius of the coaxial cable
D = outer radius of the coaxial cable

Conversion table - American Wire Gauge - mm. - mm^2

AWG N°	Diam. mm.	Area mm^2	AWG N°	Diam. mm.	Area mm^2
1	7,350	42,400	16	1,290	1,3100
2	6,540	33,600	17	1,150	1,0400
3	5,830	26,700	18	1,024	0,8230
4	5,190	21,200	19	0,912	0,6530
5	4,620	16,800	20	0,812	0,5190
6	4,110	13,300	21	0,723	0,4120
7	3,670	10,600	22	0,644	0,3250
8	3,260	8,350	23	0,573	0,2590
9	2,910	6,620	24	0,511	0,2050
10	2,590	5,270	25	0,455	0,1630
11	2,300	4,150	26	0,405	0,1280
12	2,050	3,310	27	0,361	0,1020
13	1,830	2,630	28	0,321	0,0804
14	1,630	2,080	29	0,286	0,0646
15	1,450	1,650	30	0,255	0,0503

Tnt-Audio Internet HiFi Review http://www.tnt-audio.com

Physical Layer Standards

- EIA -232 (Electronic Industries Association Standards)
  - RS – 232 (Recommended Standards)
  - 20 kbps
  - 15 m distance
- EIA -485
  - 10 Mbps
  - DDC Devices <19.2 kbps
  - Difference in voltage between two pair is measured
  - 1220 m (4000 ft)

Data Link Layer

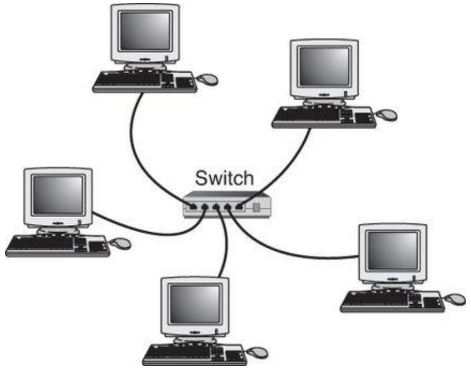
- Fair and equitable means by which multiple Computers/DDC may access physical communication medium – Network access Method
  - Master/Slave protocols – Chairperson
  - Contention Protocols – Peers, if speak at the same time , wait random number of second and speak
  - Peer to peer , token passing
  - Specified time is always given talk (but nothing to talk low efficiency)
- Master/slave protocols are more popular (on RS 485, RS 232)
  - Request/response
  - Poll/poll-response
- Contention Network access method – peer to peer
  - Used in the Ethernet
  - Protocol – carrier sense multiple access with collision detection (CSMA/CD)
  - Peer to peer – Token passing
- Token Pass - Token is used to take the right to talk
  - Widely used
  - Good for automation as we know time taken by any station

Master Slave Token passing (MSTP)

MS/TP protocol is a peer-to-peer, multiple master protocol based on token passing. Only master devices can receive the token, and only the device holding the token is allowed to originate a message on the bus. The token is passed from master device to master device using a small message. The token is passed in consecutive order starting with the lowest address. Slave devices on the bus only communicate on the bus when responding to a data request from a master device.

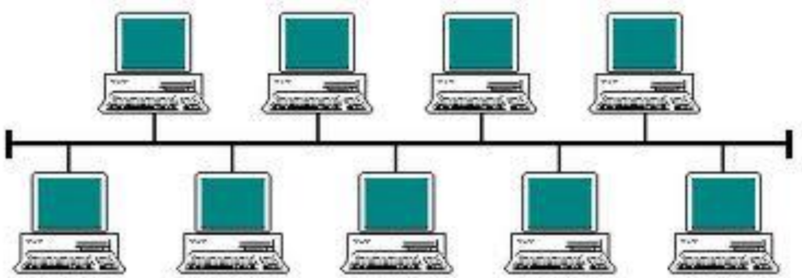
LAN Topologies

- Star Topology



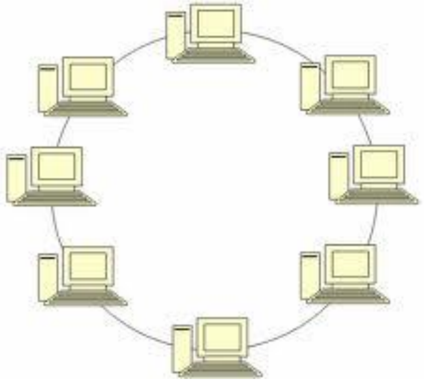
  - If hub fails communication fails
  - Expansion bit difficult
  - Simple to implement

- Bus Topology



  - Cant be grown beyond the limits
  - Cable breaks , entire network down
  - Simple and inexpensive expand
  - Resister needed at the end

- Ring Topology



  - Expensive to implement
  - Protocols are complex and devices must be intelligent
  - Very reliable and self healing in case of breakage

LAN for BMS

- LAN Standards
  - Ethernet 802.3
  - LONtalk – Neuron Chips
  - ARCNET
  - Token Ring

Wireless Technologies

- Zigbee Technology
- Wi-Fi
- Blue tooth

Type of LAN in BMS

- Centralized Network
- Decentralized Networks- based on a Token

Network Protocols

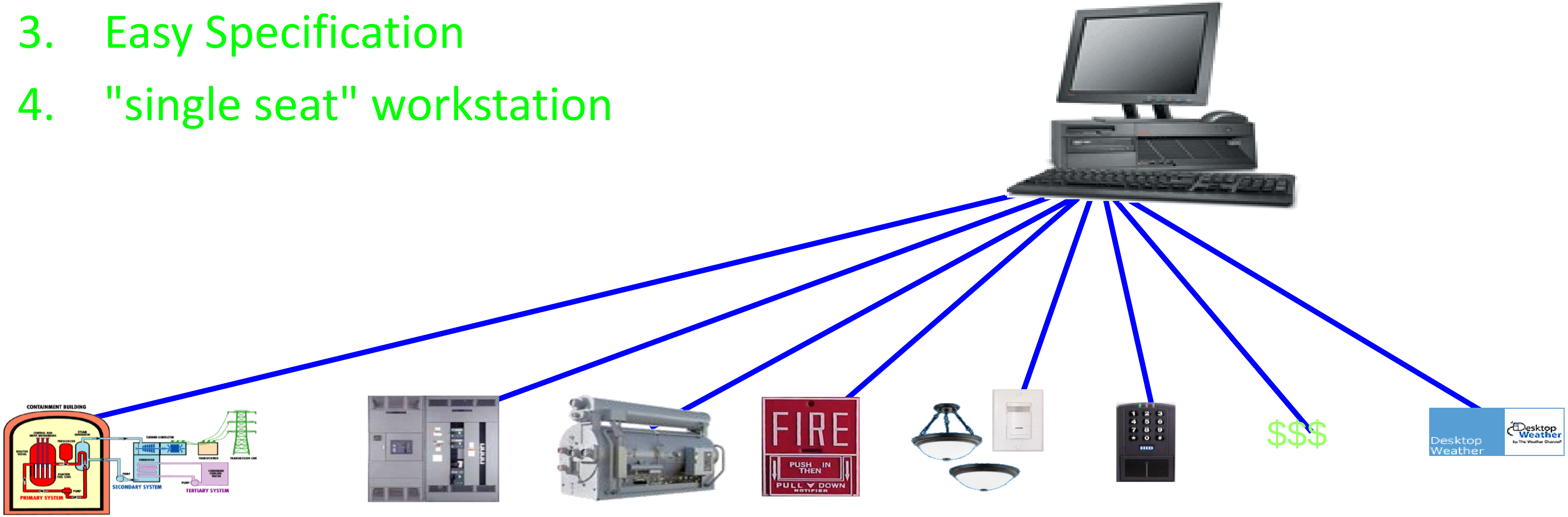
- Predefined set of rules and conventions in order to maintain error free and optimal convenient when transferring information within the network
- It defines
  - Connectors
  - Cables
  - Signals
  - Data formats
  - Error checking
  - Algorithms

Protocols in BMS

- BACnet
- LonWorks
- Modbus
- Profibus
- KNX
- OPC Server for Windows Platforms only
- WEB service Technology

The Benefits of Open Protocols?

1. Single User Interface – Many systems
2. Company Independence
3. Easy Specification
4. "single seat" workstation



Example: MS Windows OS vs. Linux

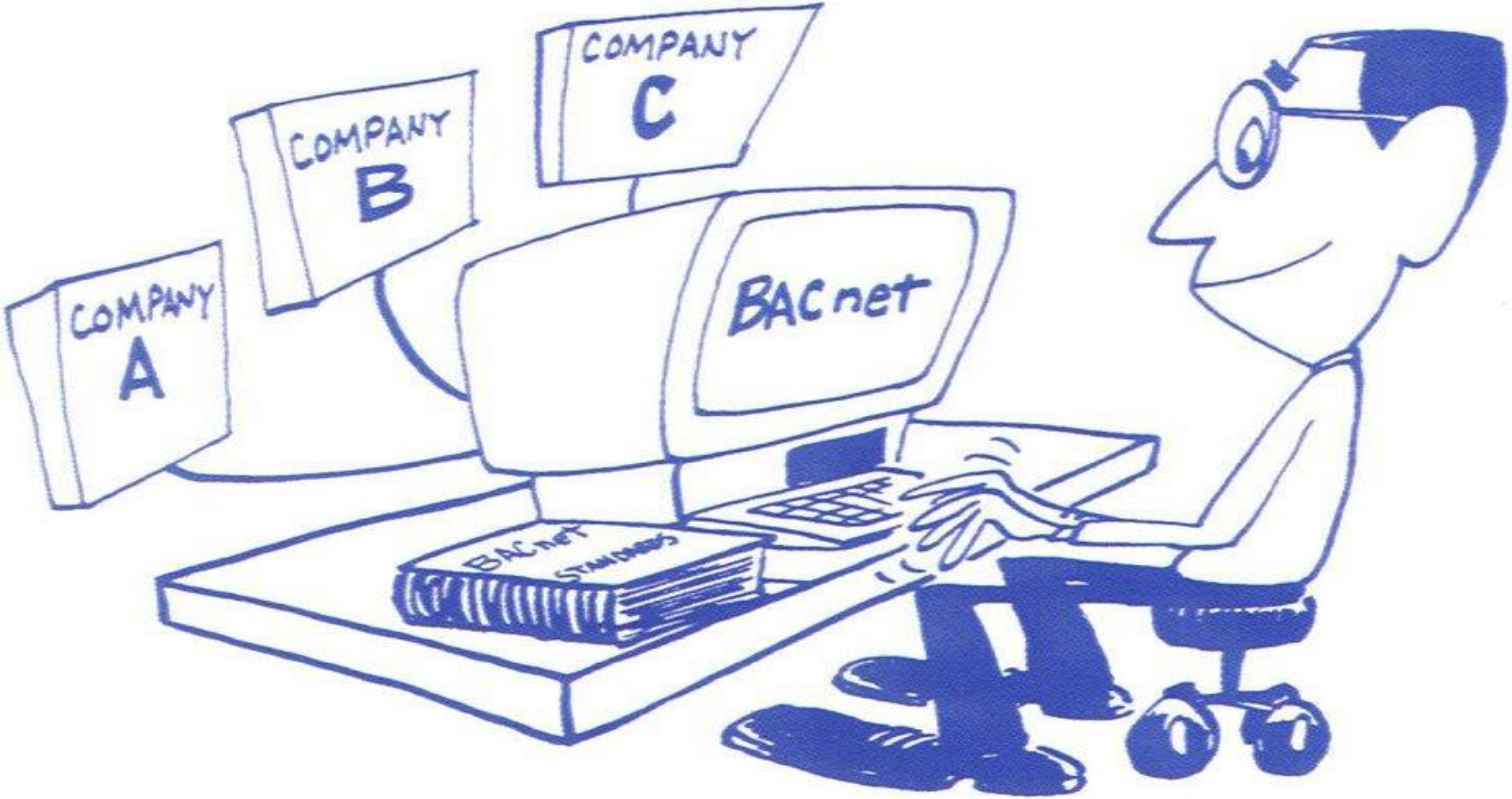
Consider the whole System

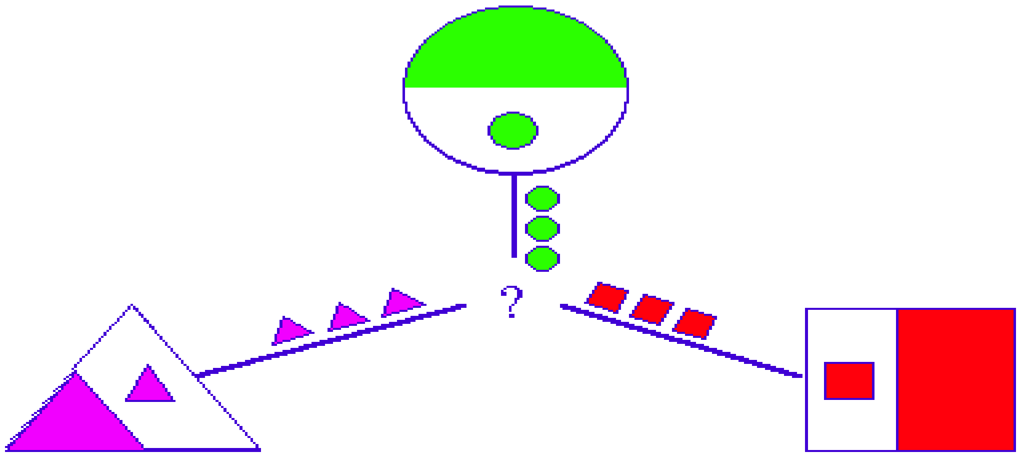
- Interoperability should happen at every system level:
  - **Device** (Ex. Temperature sensors, light sensors motors, valves, doors)
  - **Controller** (hardware device to hardware device)
  - **User Interface** (workstations, servers)
  - **Enterprise** (MIS, e-commerce, weather, utility, financial)

BACnet (<u>**B**</u>uilding <u>**A**</u>utomation and <u>**C**</u>ontrol <u>**Net**</u>work) is an Open

- Developed by ASHRAE
- Standard communication protocol is the "single seat" workstation.
- BACnet was studied and analyzed exhaustively
- Open protocol
- Original standards published in 1995
- Updated version in 2001 approved bi ISO standard 16484-5 in January 2003
- Available products include workstation, controllers, gateways, routers and diagnostic tools
- Development of a "model" for communicating was top priority.

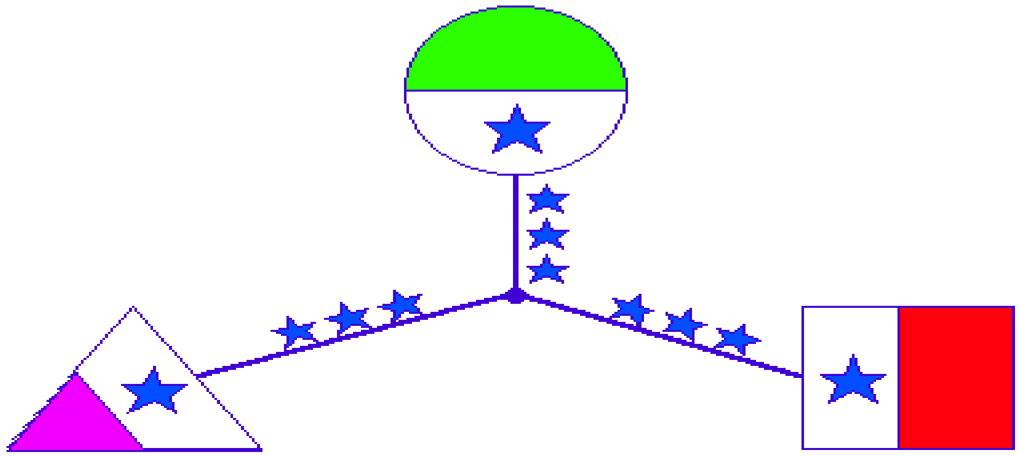
Why BACnet ?





- The clear portion of each symbol is the part of the device dedicated to data communication.

- Each device "speaks" a different language indicated by the little circles, triangles, and squares "on the wire."



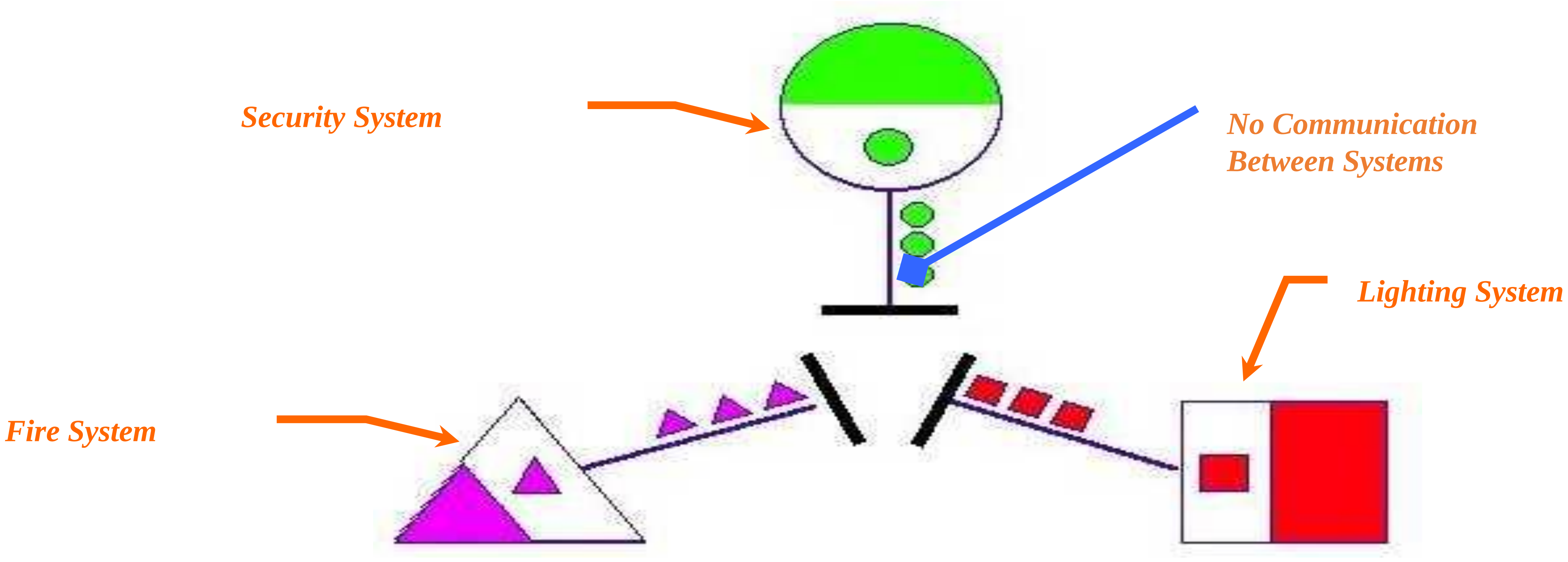
- The BACnet concept is to replace the communication portion of each device with a common, standard set of communication rules
- A common "language" - so that each device "looks the same" on the wire.

What is a Protocol?

- A protocol can be thought of as a language that electronic devices use to talk to each other.
  - Protocols are made up of a set of rules detailing:
    - The speed and format that they will transmit any data
    - What data will be transmitted
    - The medium that the information will be transmitted on (wire, RF, fiber, etc.)
- All devices in a system must follow these rules
- There are both open and proprietary protocols

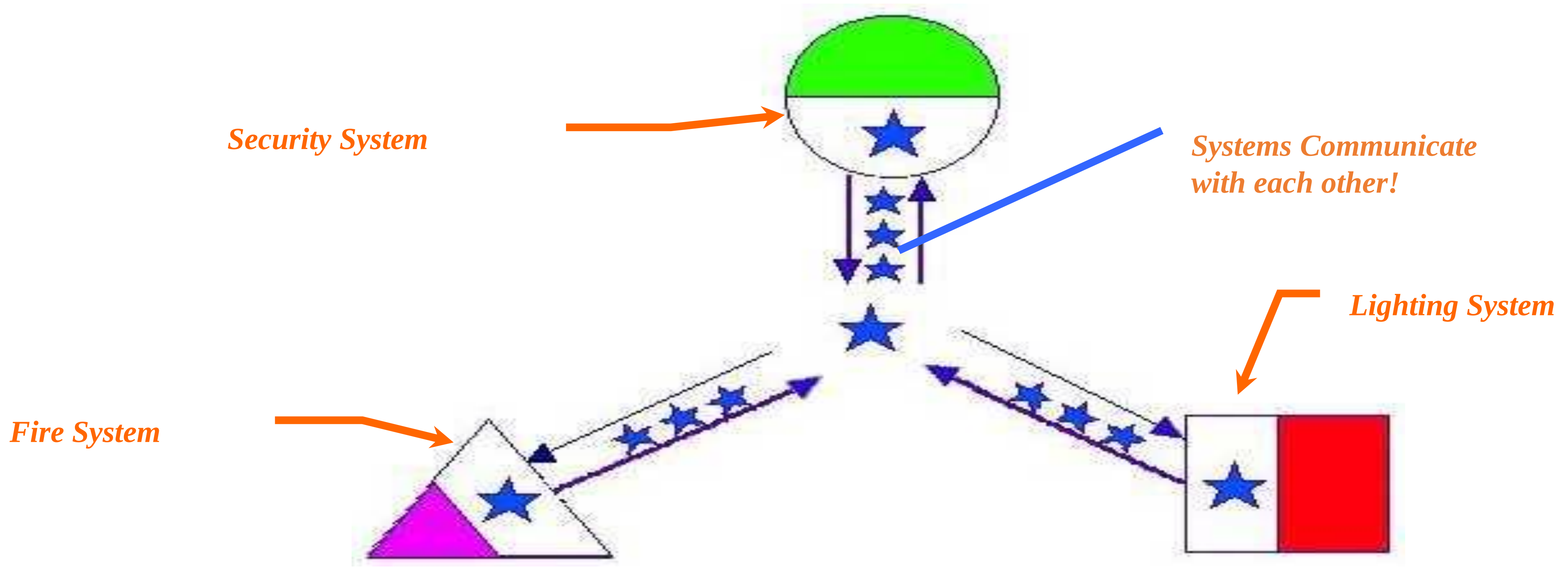
Proprietary vs. Open Protocols

<u>Proprietary Protocols</u>***:*** Each device or system "speaks" a different language as indicated by the circles, triangles, and squares



Proprietary vs. Open Protocols

Open Protocols: Systems utilize a common language in order to simplify communications. This can include programming, integration, and software applications



Proprietary vs. Open Protocols

An example of an open protocol is the North American NTSC standard for video. This allows you to use any manufacturers VCR and TV with any manufacturers videotape seamlessly to record and view information

Proprietary vs. Open Protocols

If Sony were to implement it's own rules for data transmission so that the only way your system would work would be to use all Sony components, Sony's rules for transmitting data would be a <u>proprietary protocol</u>

Industry Proprietary Protocols

- Most manufacturers implement a proprietary protocol within their own systems. This keeps each system independent of other systems
  - Lutron GRAFIK Eye Controls do not talk to ETC Wall Controls or Strand Wall Controls
  - Card Reader System A does not talk to a Card Reader Controller from System B

Benefits to Proprietary Systems

- Reduced confusion about responsibility of errors when things go wrong
- Single point of contact for any problems with a building system (one vendor)
- Software and hardware is provided and supported by the same manufacturer

Disadvantages of Proprietary Systems

- Long-term support of systems is solely dependent upon the equipment manufacturer
- If there are any bad experiences with the product manufacturer, the customer has little recourse for future additions without significant new up-front costs
- The manufacturer may not have features that a competitor’s product may offer

Industry Open Protocols

- Over the last few years, several open protocols have emerged throughout the building system integration industry. They are:

- These protocols are meant to allow different manufacturers systems or devices to ‘talk’ together

Benefits to Open Systems

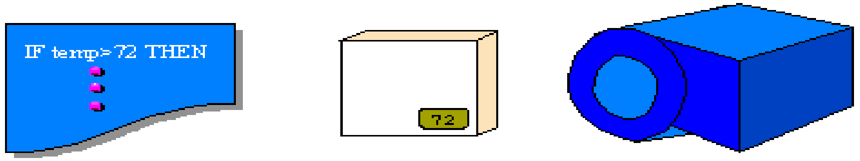
- Building owner can determine best devices or systems and seamlessly add them into existing building systems
- Systems integration is easier as every system can now ‘speak’ the same language.
- Eliminates feeling of being ‘tied-in’ to a specific manufacturer’s product, software, or a specific system programmer

Disadvantages of Open Systems

- Up-front costs of building may be higher as there are additional devices typically required for the open protocol portion of the system
- Troubleshooting building systems becomes more difficult and confusing as multiple devices and systems may be affecting the problem

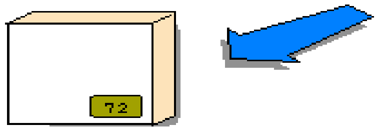
Objects

– Objects represent physical inputs, outputs and software processes



Objects

– Each object is characterized by a set of "properties" that describe its behavior or govern its operation



Object_Name	SPACE TEMP
Object_Type	ANALOG INPUT
Present_Value	72.3
Status_Flags	Normal, Out-of-Service
High_Limit	78.0
Low_Limit	68.0

- This is accomplished by introducing **"objects."** An object is simply a collection of information related to a particular function that can be uniquely identified and accessed over a network in a standardized way.
- All information in a BACnet system is represented by such data structures. The object concept allows us to talk about and organize information relating to physical inputs and outputs, as well as non-physical concepts like software, or calculations.
- Objects may represent single physical ?points,? or logical groupings of points that perform a specific function. Objects meet the design requirement of providing each device with a common "network view," i.e., all objects, regardless of the machine in which they reside, look alike!

All BACnet objects provide a set of properties which are used to get information from the object, or give information and commands to an object.
You can think of an object's properties as a table with two columns. On the left is the name or identifier for the property, and on the right is the property's value. Some properties are read only meaning that you can look at the property value, but not change it. Some properties can be changed (written).

The slide shows an example of a temperature sensor, which might be represented as a BACnet Analog Input object. The example shows a few of the properties which might be available with this object, although in practice there would be many more properties than those shown.
The object has a name property (?SPACE TEMP?) and an object type (ANALOG INPUT).

The Present_Value property tells us what the temperature sensor is reading at this moment (72.3 degrees). Other properties show us other information about the sensor object, such as whether it appears to be functioning normally, or High and Low Limits for alarming purposes.

Objects

BACnet defines a collection of 23 standard object types

- Binary Input
- Binary Output
- Binary Value
- Analog Input
- Analog Output
- Analog Value
- Averaging
- LifeSafetyZone
- Multi-state Input
- Multi-state Output
- Multi-state Value
- Loop
- Calendar
- Notification Class
- Command
- LifeSafetyPoint
- File
- Program
- Schedule
- Trend Log
- Group
- Event Enrollment
- Device

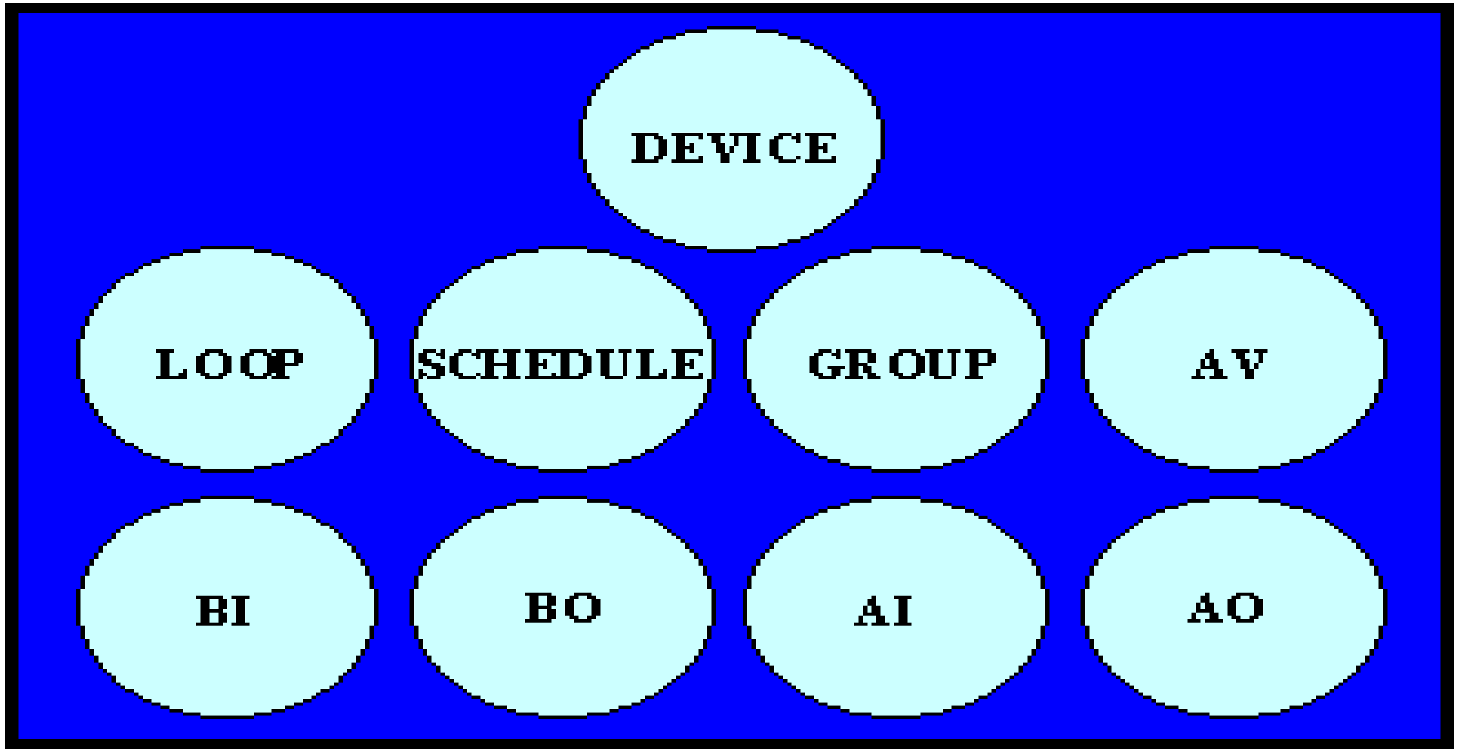
Although there are thousands of potentially useful object types which might be found in building automation, BACnet defines 23 standard object types in some detail.

A BACnet standard object is one whose behavior, in terms of which properties it provides and what they do, is defined in the BACnet standard.

This set of standard objects represents much of the functionality found in typical building automation and controls systems today.

BACnet devices are only required to implement the Device object. Other objects are included as appropriate to the device's functions.

BACnet Device



A "BACnet Device" is simply a collection of objects that represents the functions actually present in a given real device.
While the slide shows only one instance of each kind of object in the example device, a more typical BACnet device might have 16 BI and BO objects, 2 or 3 Schedule objects, and so on.

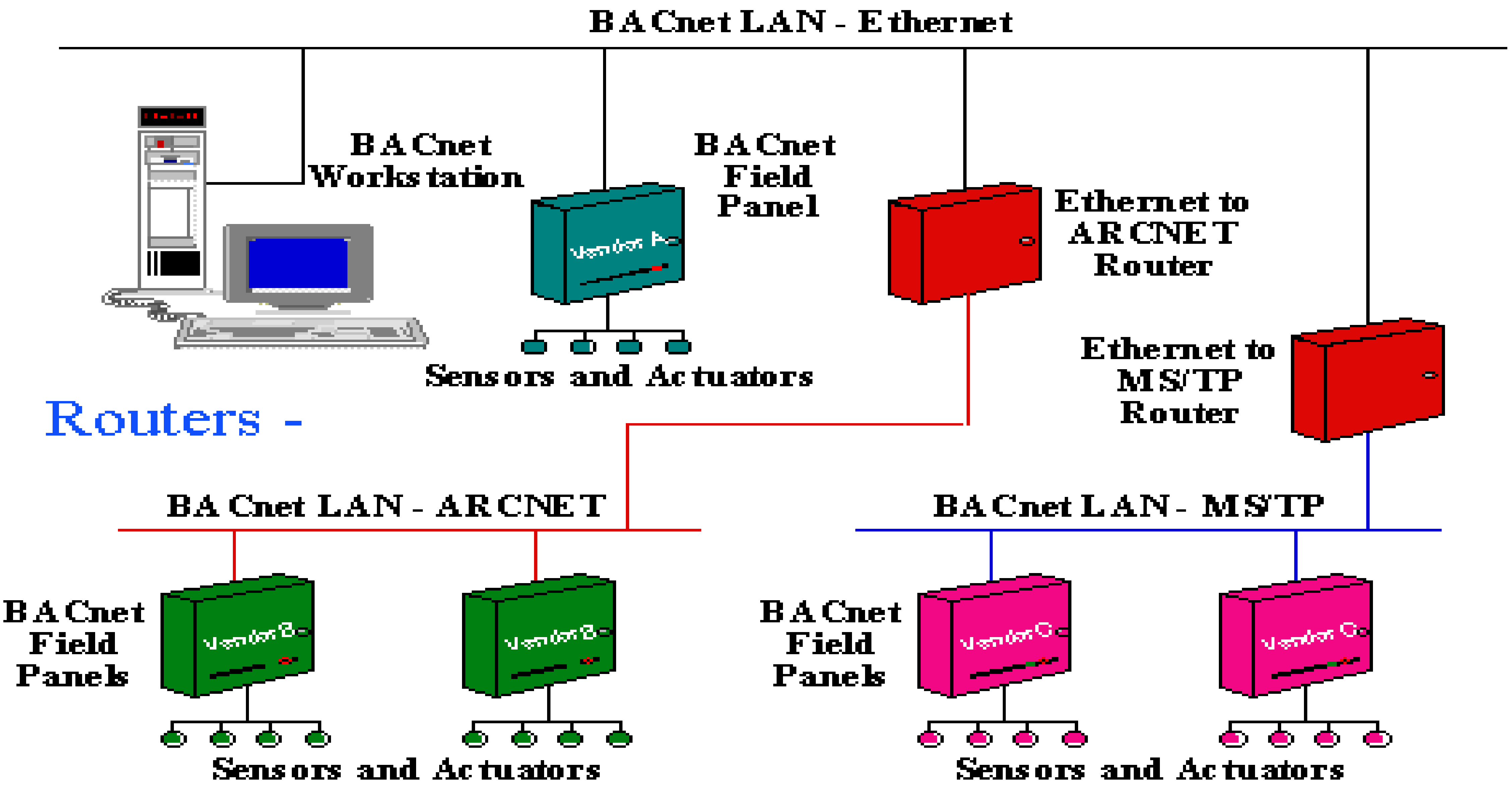
The second part of the development challenge was to agree on what kinds of messages building automation and control devices might want to send to each other.

Since BACnet is based on a "Client-Server" communication model, these messages are called "services" which are carried out by the server on behalf of the client.

LAN Options

- Ethernet
- ARCNET
- Master-Slave/Token-Passing (MS/TP)
- Point-to-Point (PTP)
- Echelon's LonTalk
- BACnet/IP and "Virtual LANs" (allows for TCP/IP, ATM, etc.)

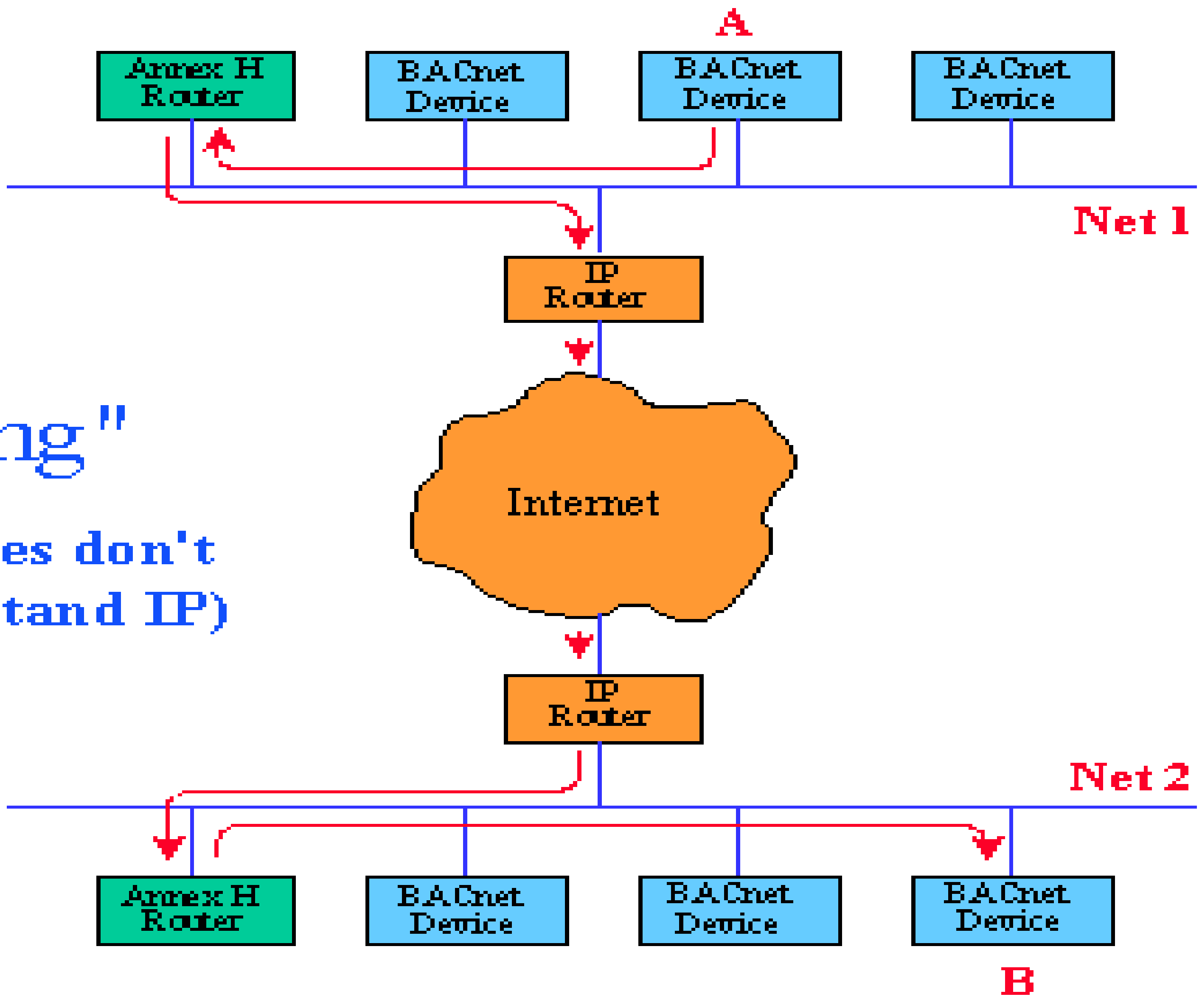
Routers -



"re-package" BACnet messages and re-transmit them unchanged

IP "tunneling"

(BACnet devices don't need to understand IP)



Although there are thousands of potentially useful object types which might be found in building automation, BACnet defines 23 standard object types in some detail.

A BACnet standard object is one whose behavior, in terms of which properties it provides and what they do, is defined in the BACnet standard.

This set of standard objects represents much of the functionality found in typical building automation and controls systems today.

BACnet devices are only required to implement the Device object. Other objects are included as appropriate to the device’s functions.

- Developed within ASHRAE committee SSPC-135 since 1987
  - ASHRAE guidelines guarantee open process
  - Membership of end-users and producers
  - Adopted by ANSI, ISO and CEN
    - ISO 16484-5
  - Freely distributed
  - No Licenses, Hardware Independent
  - Used worldwide by hundreds of vendors
  - ASHRAE Standard Project Committee (SPC)

How was BACnet developed?

- Developed a standard "network view" or model to which each vendor can "map" his device.
- Developed standard "messages" or services that use the model and carry out other common functions.
- Agreed upon the encoding into "ones and zeros".
- Agreed upon physical, data link, and networking standards, i.e., LANs, that the vendors are willing to support.

Field levels in a general BMS

- The field Level includes the instrumentation interfaced to the Automation Level DDC controllers such as the temperature, humidity, level, pressure sensors and switches etc.
- It includes the final control elements such as the valve and damper actuators and the control relays.
- The control and monitoring signals between the Automation Level controllers and the Field Level components shall be via industry standard analogue ranges, such as 0 to 5V, 0 to 10V, 4 to 20 mA, switched 0 and 5V, switched 0 and 10V, etc.

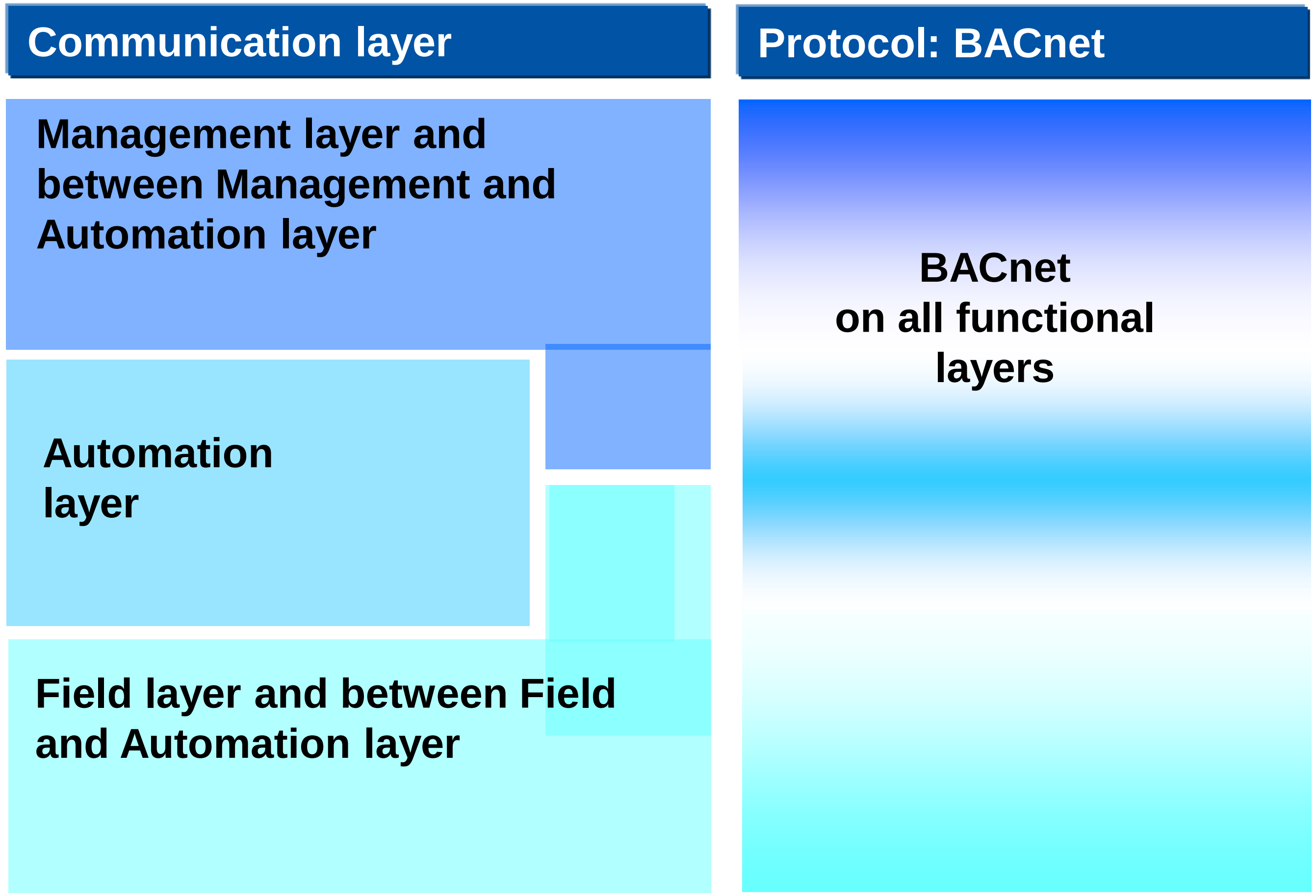
For an example, A temperature sensor will send an analog signal proportional to the temperature being measured (from 0 to 10 volts for example).

The signal is interpreted by the DDC control logic at the "Automation level" as an Analog Input Object.

This command or action will then be in the form of a BACnet Object.

The instruments at the field level needs not "understand" or "interpret" the signals it is sending or receiving.

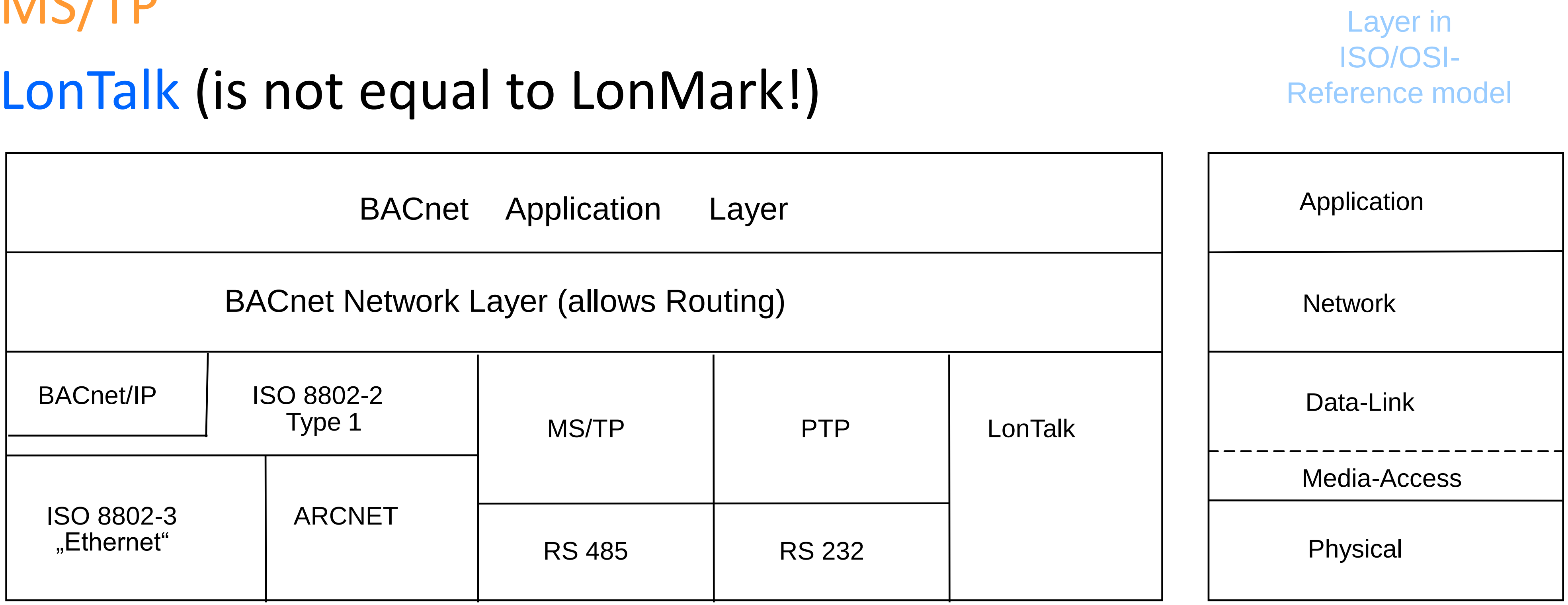
BACnet, ISO Norm 16484-5



BACnet –
DIN EN ISO 16484-5
Includes references to
EIA-709.1 LonTalk
EN 50090 EIB/KNX

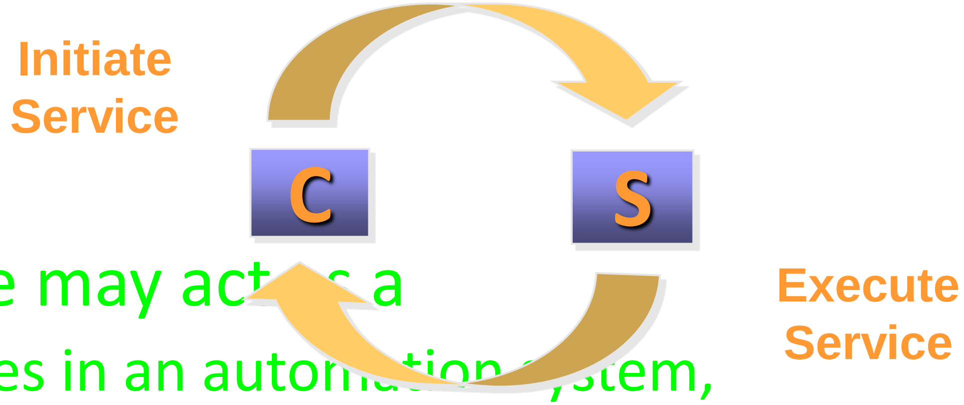
BACnet Networking Options

- Ethernet
- BACnet over IP
- Serial (RS232/RS485)
- ARCnet
- MS/TP
- LonTalk (is not equal to LonMark!)



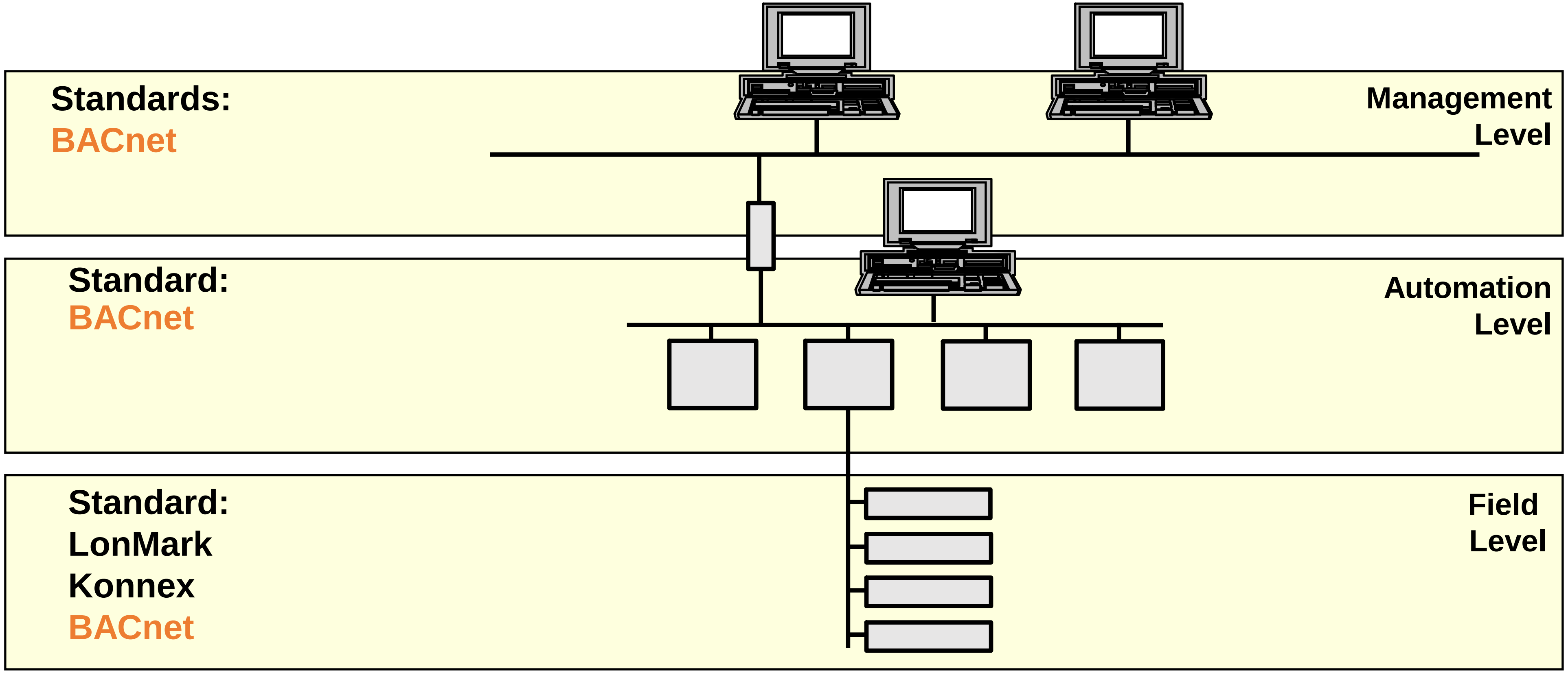
BACnet Client/Server architecture

- A BACnet device may trigger a service or can react on a service request:
  - Client: Requests services (Service user)
  - Server: Offers services (Service provider)



- A DDC-system for example may act as a
  - client for various field devices in an automation system,
  - server for other DDC-systems or for a BMS (Building Management System) that requests specific data or alarms

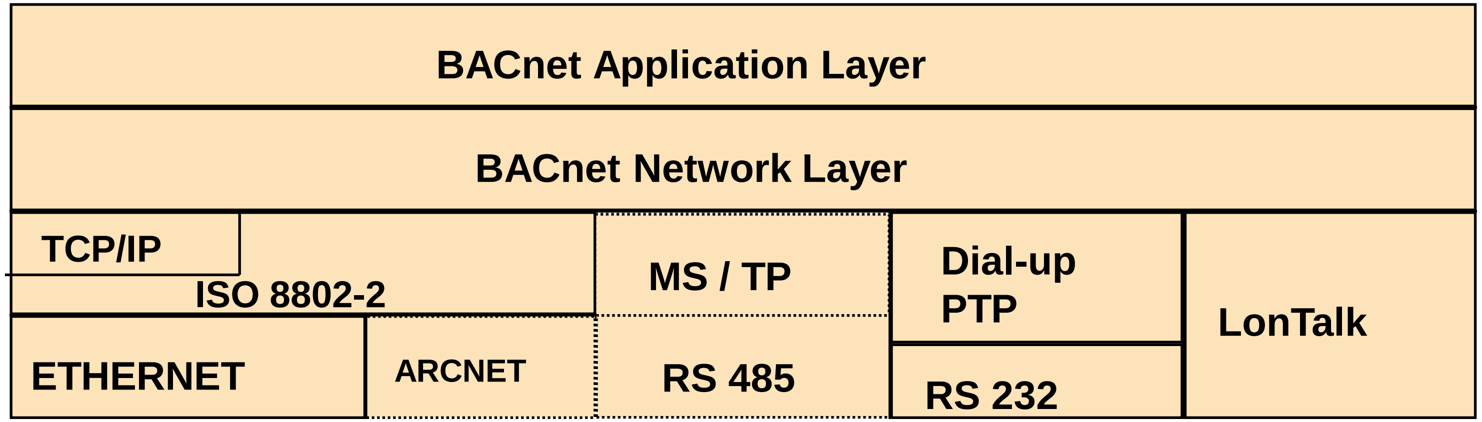
- Positioning of BACnet



Protocol Layers and their Meaning

- Data Transport
  - Network Layer
  - Link Layer
  - Physical Layer

- Data Interpretation
  - Application Layer
    - Services
    - Objects



Data Transport: The Bus

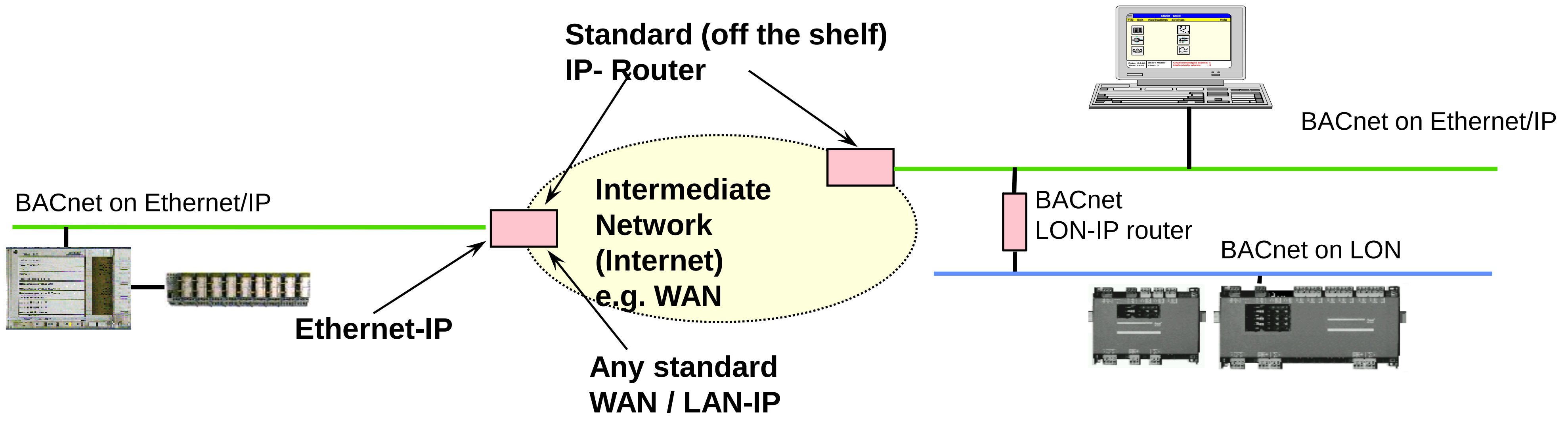
- Flexibility by different media
- Media request for distinct link layers
  - Ethernet / TCP/IP: TCP/IP provides access to company networks
  - LonTalk: including all media defined there
  - Point to Point (PTP): mainly used for modem connections
  - Arcnet
  - MS/TP

Data Transport: The Network Layer

- BACnet provides a homogeneous network layer
  - Routing through different busses is possible, eg. from a modem link (PTP) through Ethernet to all LonTalk segments
  - Annex J of the BACnet Standard defines the routing through a TCP/IP network. This ensures the integration of a BACnet network into a company network
- The homogeneous network layer is important for the flexibility of BACnet internetworking

Example: Networks

- Routers:
  - Are working on network layer, i.e. they are totally independent from the application layer
  - Standard routers in IP-networks, i.e. BACnet can be integrated in any given company network



Standard BACnet device profiles

- B-OWS BACnet Operator Workstation
- B-BC BACnet Building Controller
- B-AAC BACnet Advanced Application Controller
- B-ASC BACnet Application Specific Controller
- B-SA BACnet Smart Actuator
- B-SS BACnet Smart Sensor
- B-GW BACnet Gateway

Application: Objects

- Datapoint objects
  - Analogue in / out / value
  - Binary in / out / value
  - Multistep in / out / value
  - Accumulatior / Pulse Converter
- Alarm handling objects
  - Notification class (distribution of alarm messages)
  - Event enrollment (defining the alarm conditions)
- Miscellaneous objects
  - Device object (provides device informations)
  - Schedule object / calendar object
  - Trenddata object
  - Loop object
  - Program / file object
  - Virtual terminal object

Application: Object Properties

- Properties are parameters of objects
  - Examples: present value, alarm limits, name, status
- Bacnet distinguishes between mandatory and optional properties
- Properties may either be read only or also writable, i.e. modifyable by BACnet services)

object-identifier	[75]	BACnetObjectIdentifier,
object-name	[77]	CharacterString,
object-type	[79]	BACnetObjectType,
present-value	[85]	REAL,
description	[28]	CharacterString OPTIONAL,
device-type	[31]	CharacterString OPTIONAL,
status-flags	[111]	BACnetStatusFlags,
event-state	[36]	BACnetEventState,
reliability	[103]	BACnetReliability OPTIONAL,
out-of-service	[81]	BOOLEAN,
update-interval	[118]	Unsigned OPTIONAL,
units	[117]	BACnetEngineeringUnits,
min-pres-value	[69]	REAL OPTIONAL,
max-pres-value	[65]	REAL OPTIONAL,
resolution	[106]	REAL OPTIONAL
cov-increment	[22]	REAL OPTIONAL,
time-delay	[113]	Unsigned OPTIONAL,
notification-class	[17]	Unsigned OPTIONAL,
high-limit	[45]	REAL OPTIONAL,

and so on

Application: Services

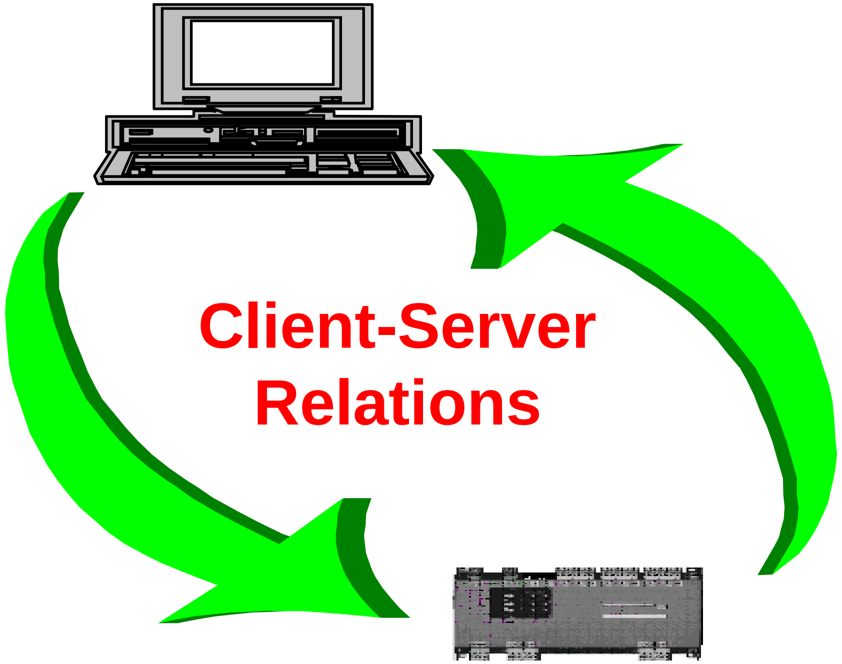
- BACnet offers 38 services on application layer
  - The services are partitioned in these 6 classes:
    - Alarm handling
    - Object access
    - Device management
    - Network security
    - File access
    - Virtual terminal
  - Examples are: read, write, change of value notification, time synchronisation alarm messaging

Models: Real Device and BACnet Objects

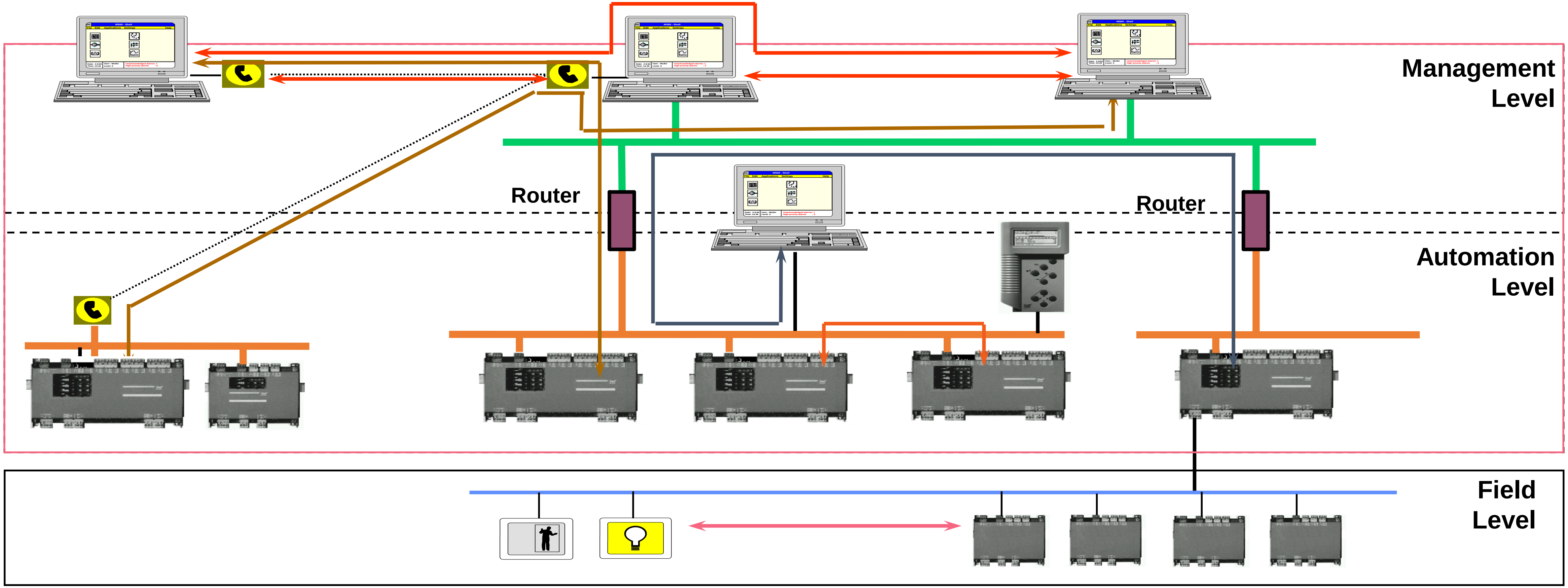
- BACnet objects are modelling the view onto a device through the network
  - BACnet objects don’t define internal functionality of devices (algorithm)
  - BACnet objects give the outside view onto device functions
  - Example: The BACnet loop object is defined in a way, that different loop algorithm e.g. PI, PID, sequence, predictive control.. can be mapped

Models: Client - Server Relations

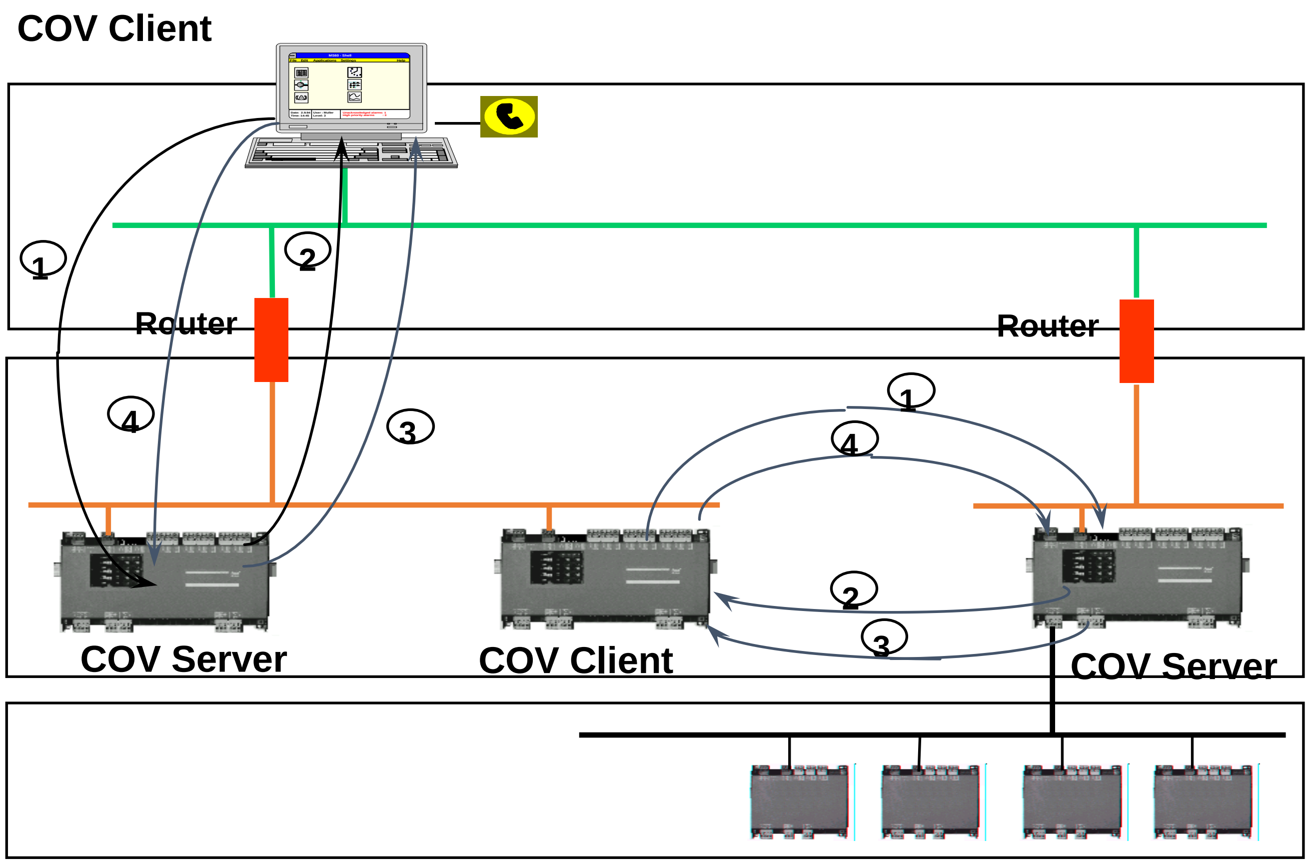
- The client is claiming services of the server
  - The client
    - subscribes for changes of values
    - gives order for trend data registration
    - defines alarm limits
  - The server maintains an image of the device functionality and executes the services



Model: Peer to Peer Communication



Example: COV-Handling



1- Client subscribes for a value (data point) of the server
2. Server returns the value together with the acknowledgement
3. Server returns the value whenever it changes
4. Client renews or cancels subscription

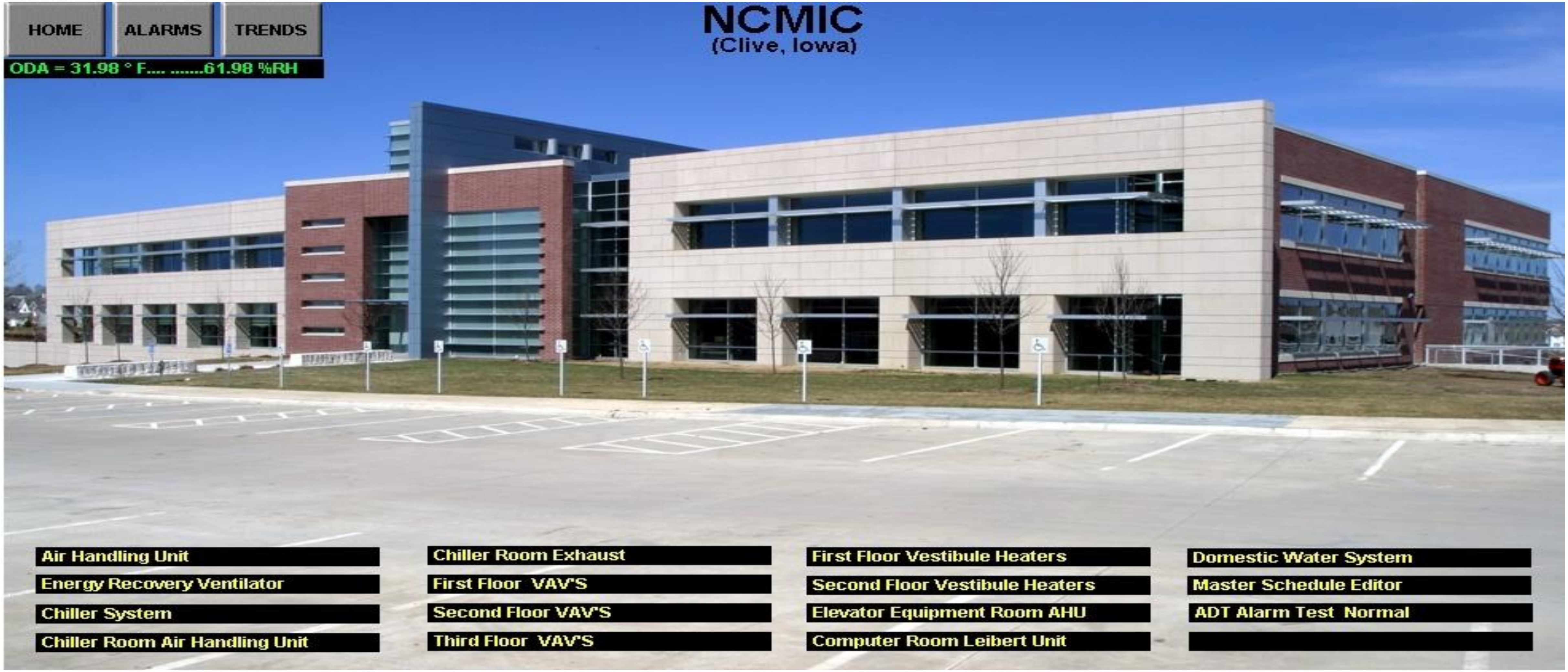
Extensability of the BACnet Protocol

- The BACnet protocol is designed in a way, that extensions are easily possible
  - Extensions by the BACnet Standard Committee (SSPC-135)
  - Proprietary extensions by manufacturers
- Extensible are
  - Objects: new objects or new properties
  - New services
- Therefore BACnet is future proof

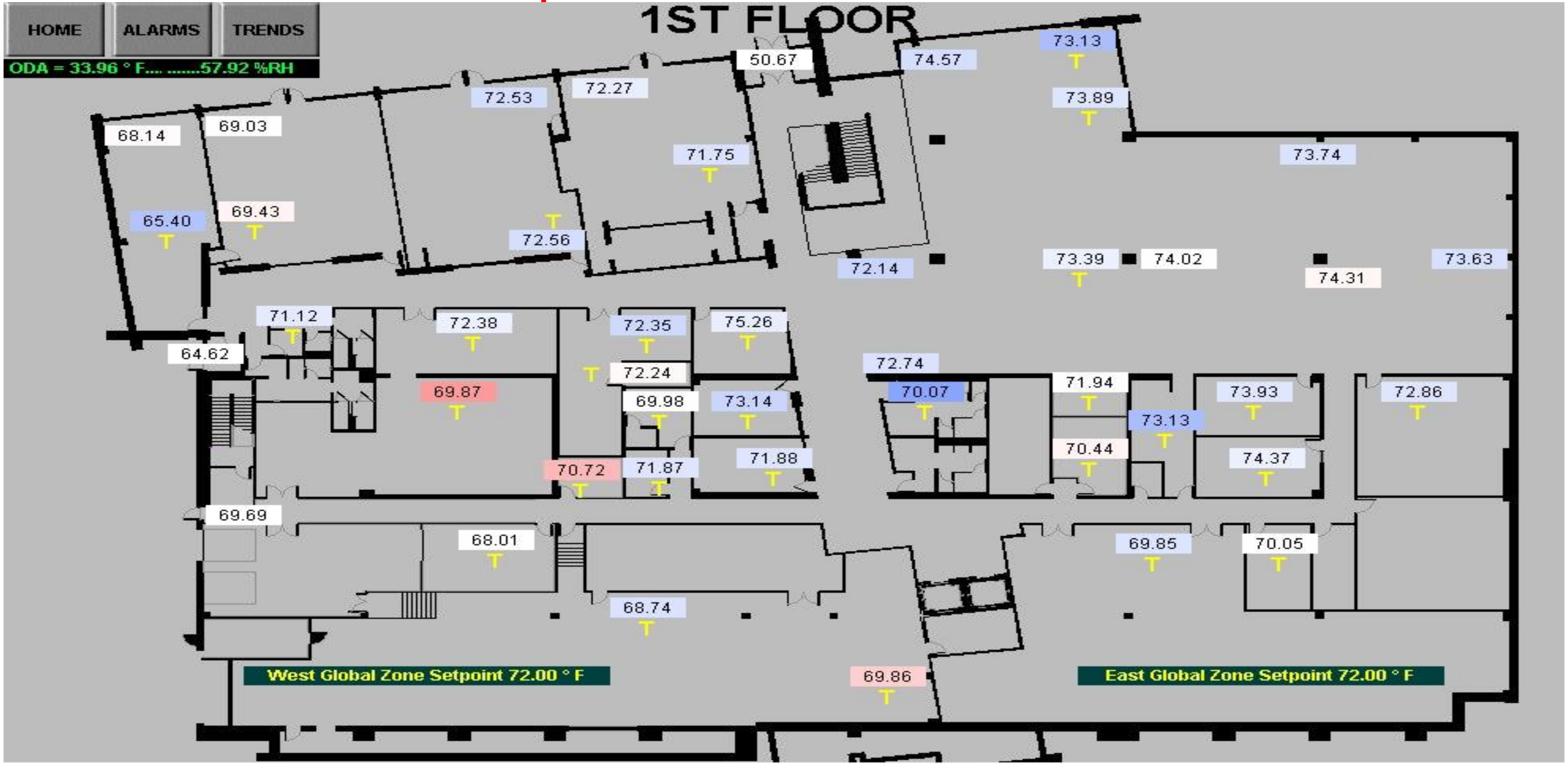
Compatibility and Conformity

- Compatibility of BA-systems - Interoperability
  - BACnet interoperability Building Blocks BIBBs and device profiles provide an overview
  - PICS give the details: client- or server-role, object types, bus types....
- Conformity to the standard - a premise
  - Only with conformity to the standard interoperability becomes possible
  - ASHRAE is defining test procedures
  - BACnet Interest Group is about to define testbeds and a certification process

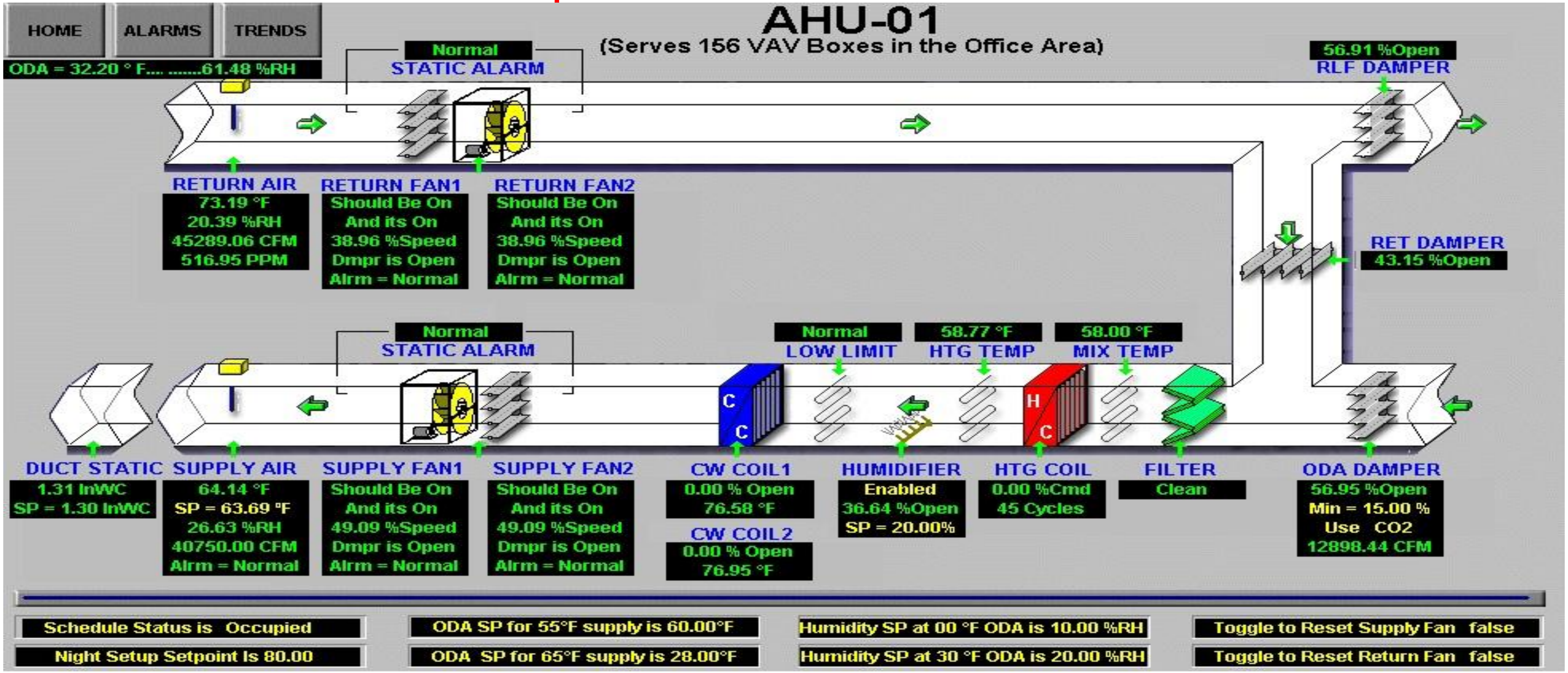
Case study: GUI Development - Web Based Graphics



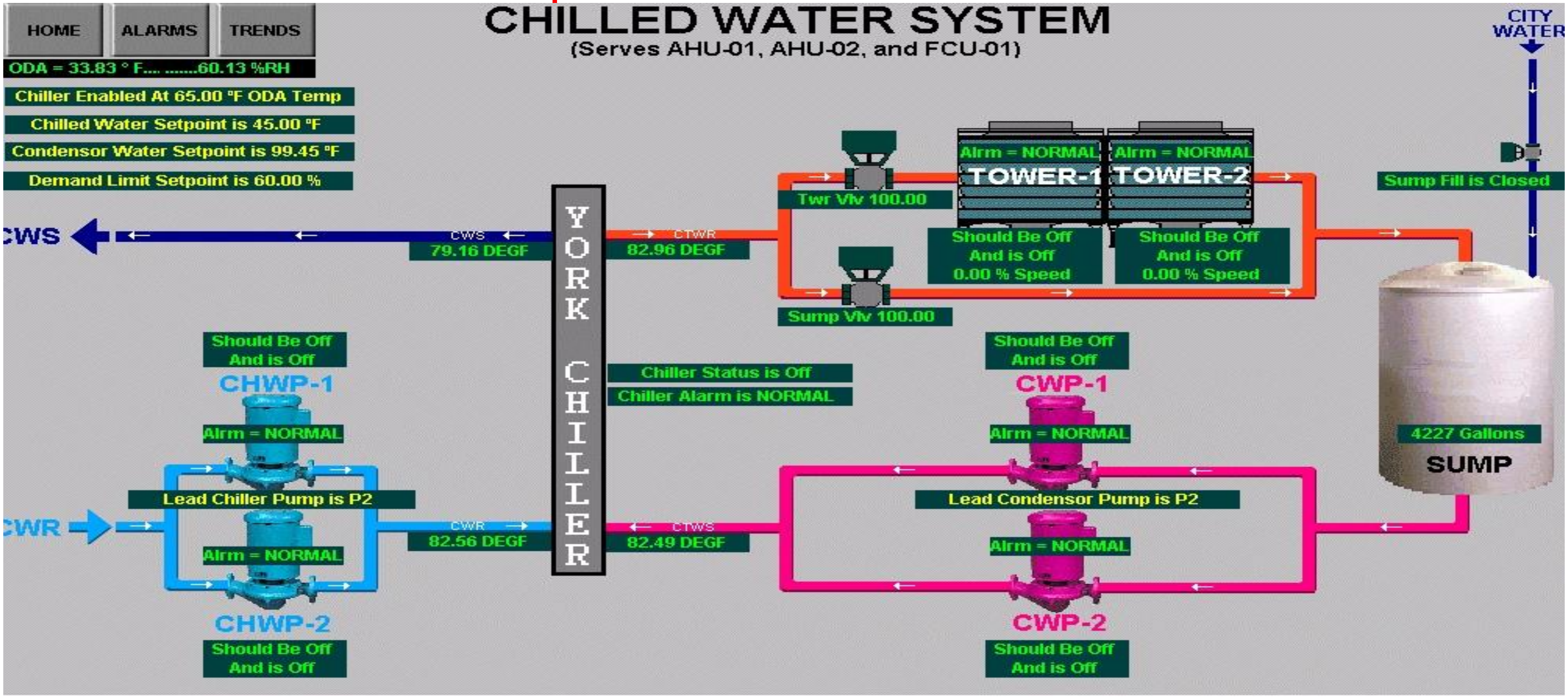
Web Based Graphics



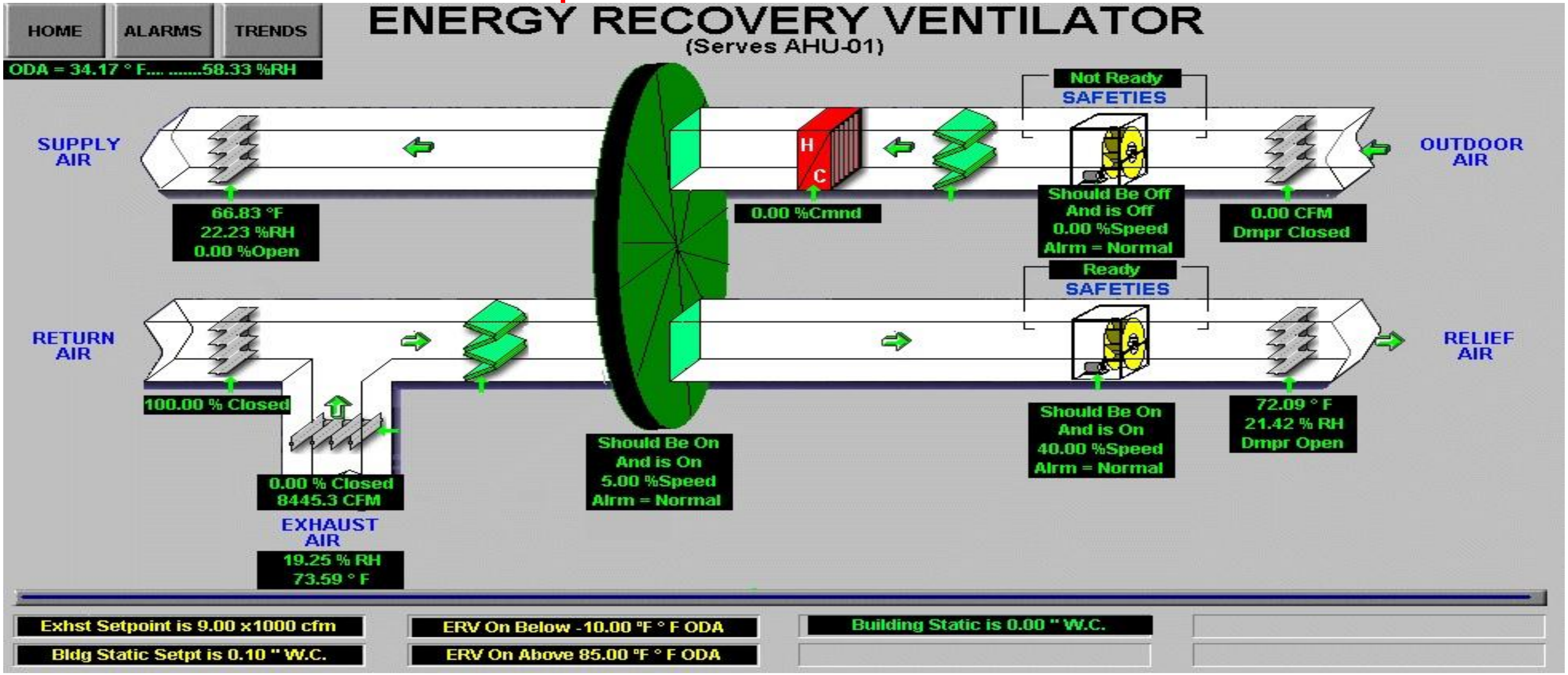
Web Based Graphics



Web Based Graphics



Web Based Graphics



Integration

- Bringing all building control systems onto one network protocol with common interface
- Very hot industry topic with new integrators coming to market
- Offer of a common site-wide user interface is very, very attractive
- Many tools available, BACnet, LonTalk, ModBus, and special programming.
- All options have to be leveraged in order to gain the benefit

Integration

- Can be difficult and expensive
- Determine the value of the information to measure against the cost
- Distance increases value if maintenance is centralized
- WFHM Homebase Example…

Documentation

- Design must be clearly defined prior to installation with performance criteria and proscriptive requirements
- Clearly defined sequences based on good engineering fundamentals
- Sequences must coordinate, not fight
- Right list of acceptable vendors
- Detailed point listing
- Detailed product requirements
- DM Library example…

Sequence of Control

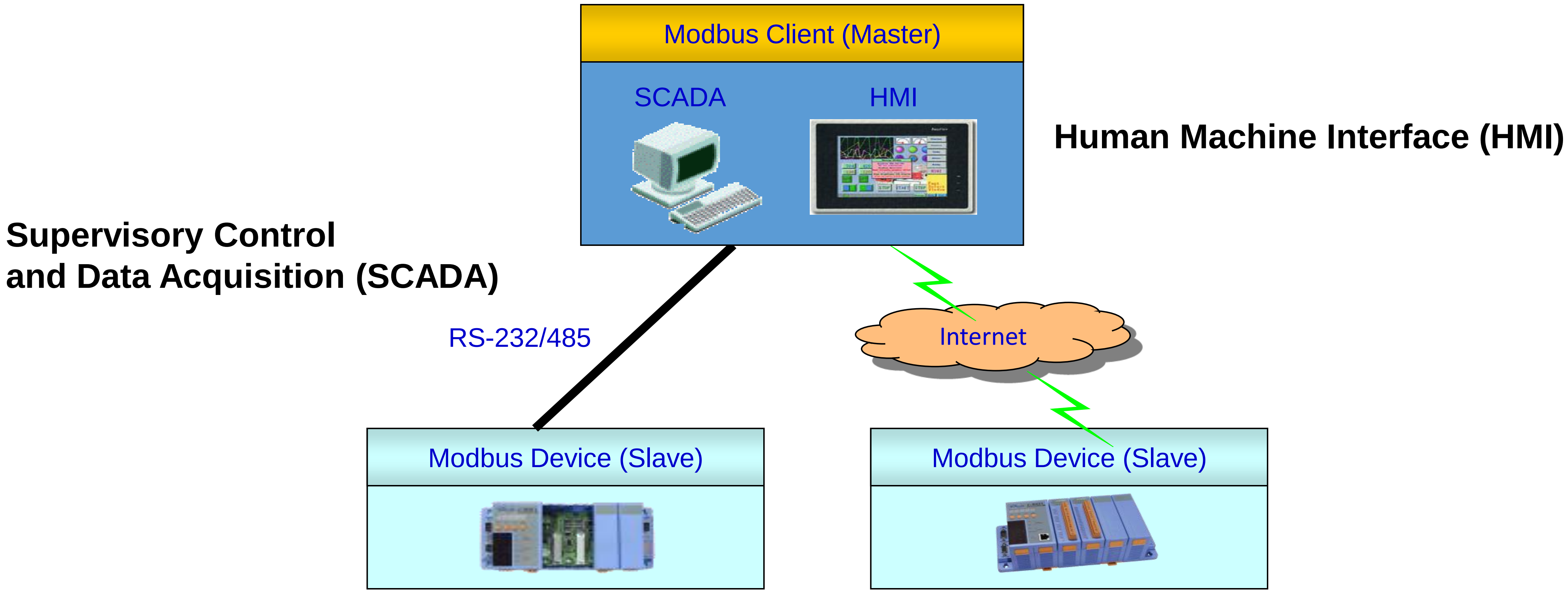
- Word Picture of how the system is to control the equipment
- Insurance that you will get what you want and not what the vendor wants
- Document to measure submittals compliance
- Sequence should include description of:
  - all operating modes
  - how equipment is regulated or modulated to match loads
  - how equipment starts and stops; safeties
  - criteria for changing or selecting modes
- DM Library example…

What is Modbus ?

- An open data communication protocol
- Published by Modicon
- http://www.modicon.com
- Open structure
- Flexible
- Widely known
- Supplied by many SCADA and HMI software
- 2 serial transmission modes:
  - ASCII ➔ 10 bits
  - RTU (Binary) ➔ 11 bits
- Communication interface
  - RS-232/485
  - Ethernet (TCP/IP)

- Modbus Organization (http://www.modbus.org/default.htm)

Application Structure (general)



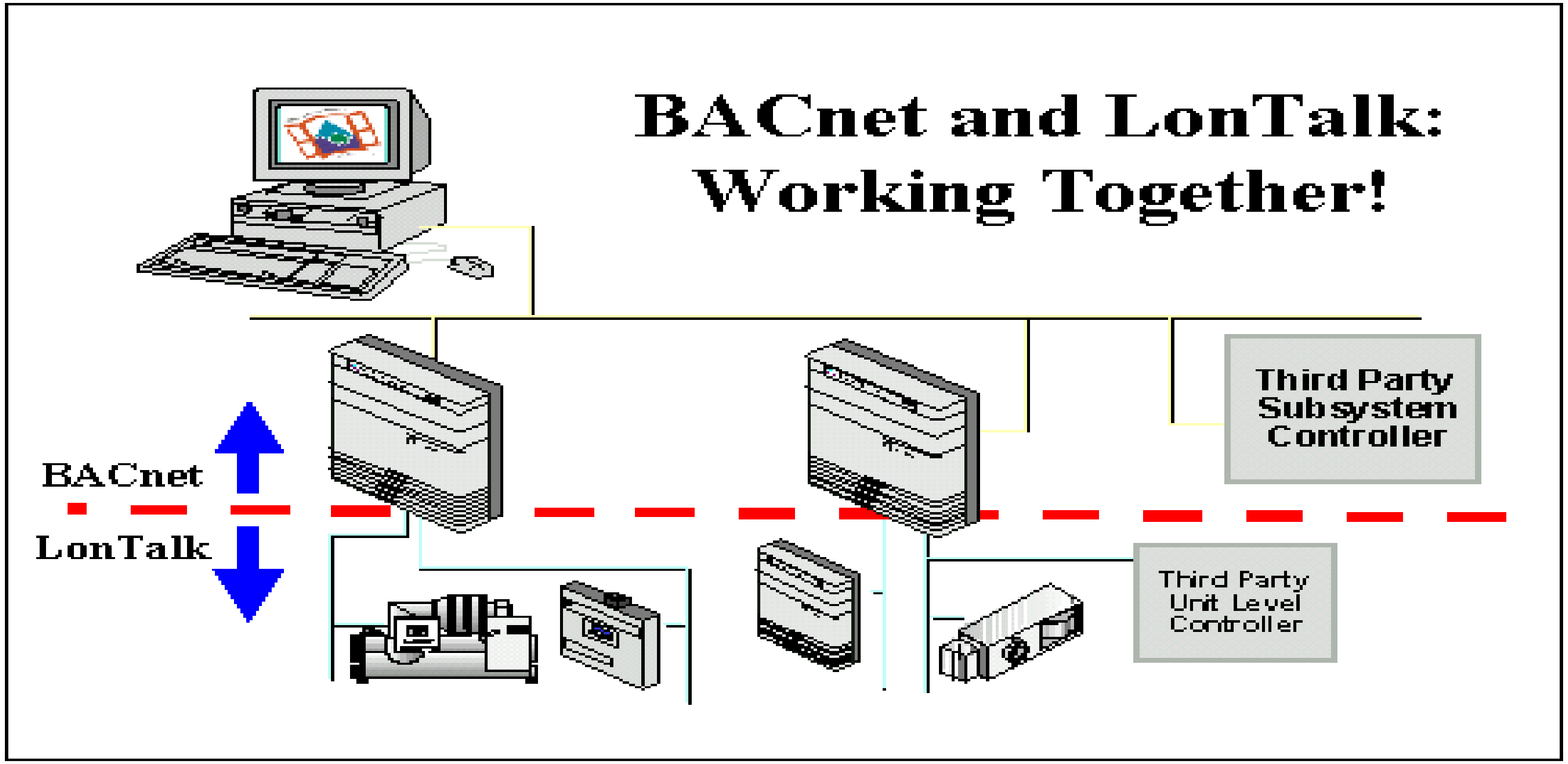
on LonTalk

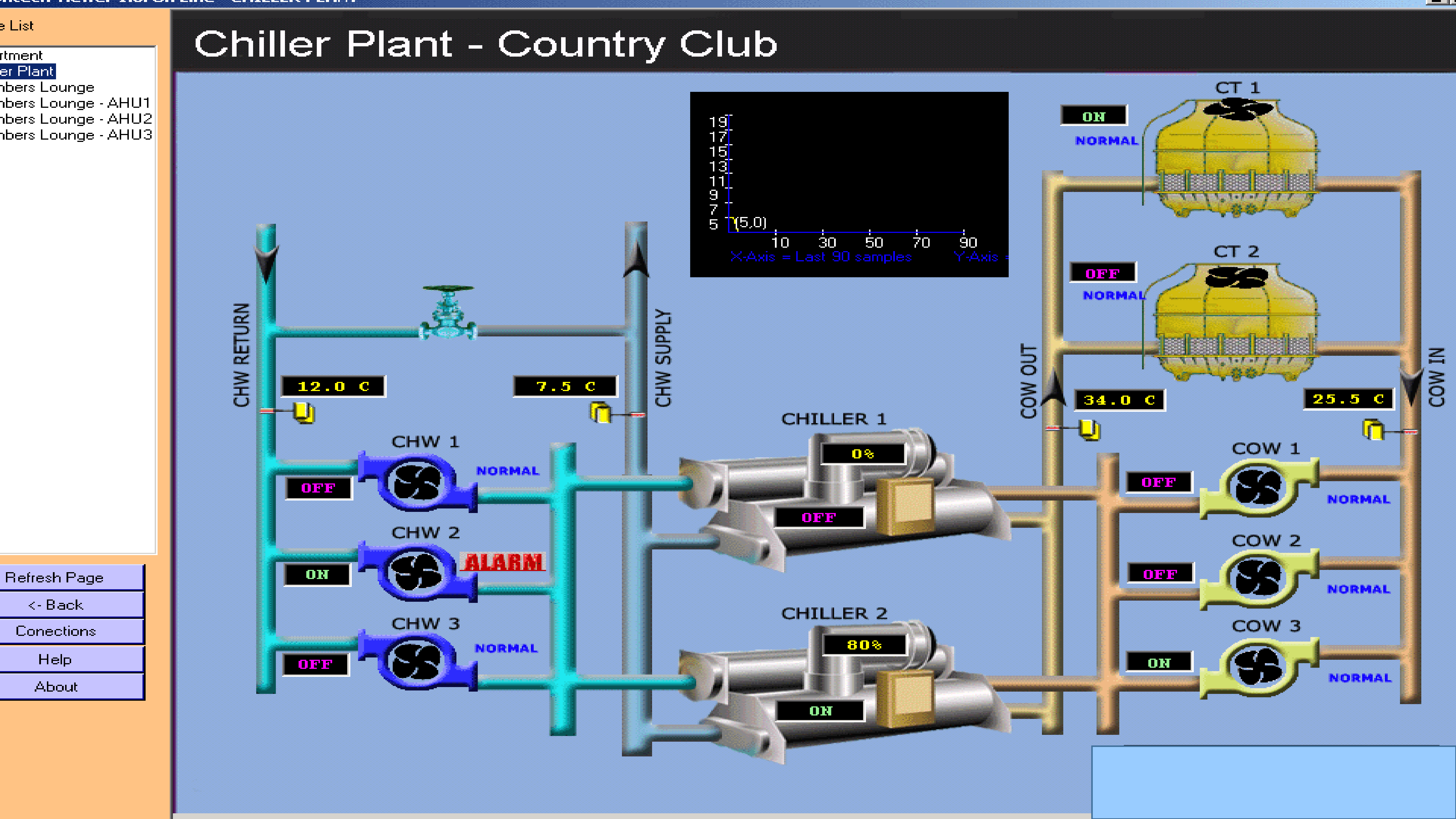
- Has become a very powerful integration tool for devices and equipment
- Mostly intended for device communication
- Robust and very well defined and controlled
- Again, almost universally adopted for some devices and sensors
- Easy to specify with high confidence in performance
- Again, not initially designed for internet, but protocols have been added

[redacted]

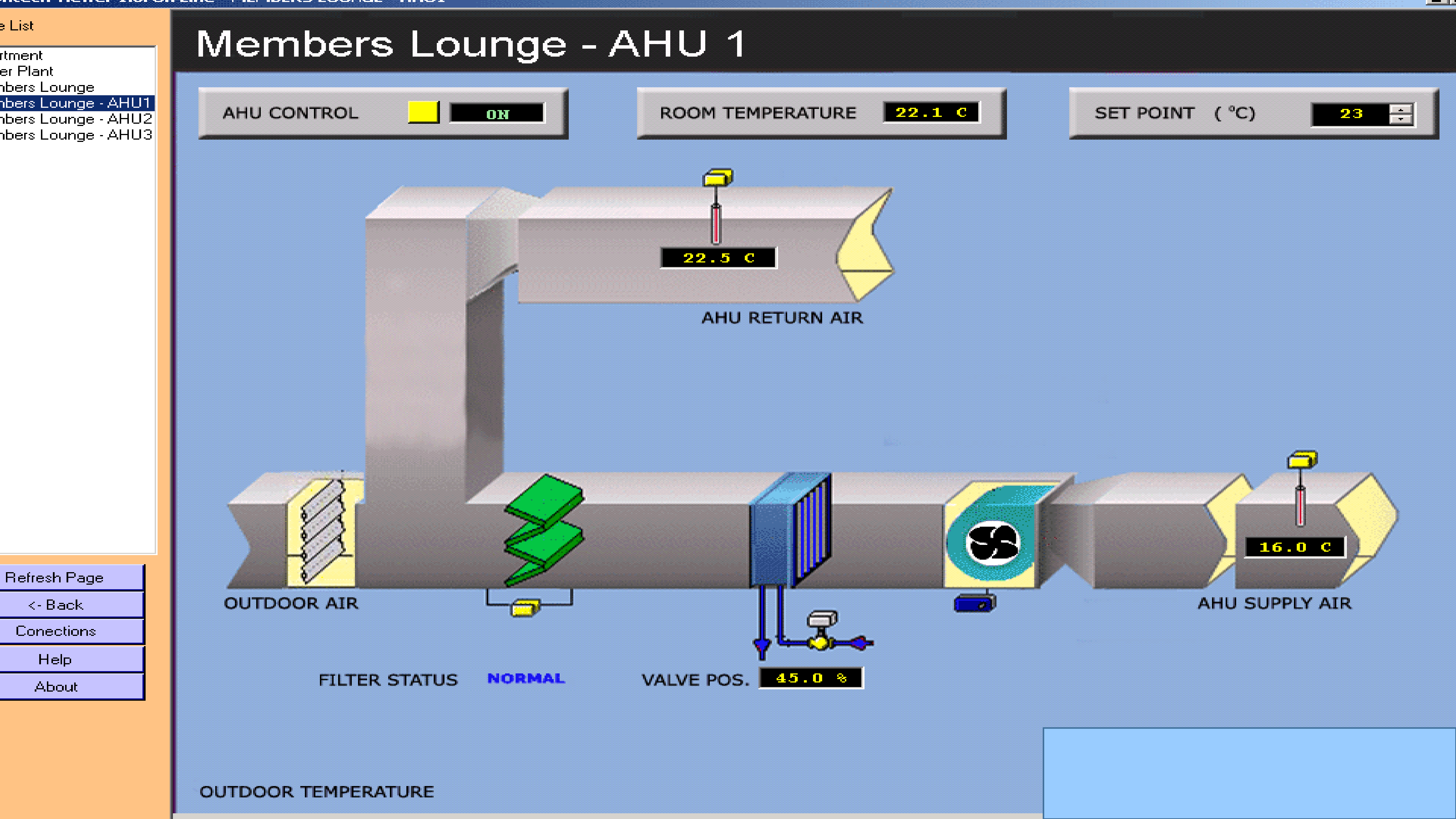
- Some packaged equipment now coming with LonTalk
- Some systems are now Lon resident
- Give basic information required for control
- If something more complex, or outside the “profile” of the device, *that* vendors software tool will be needed.

BACnet and LonTalk!



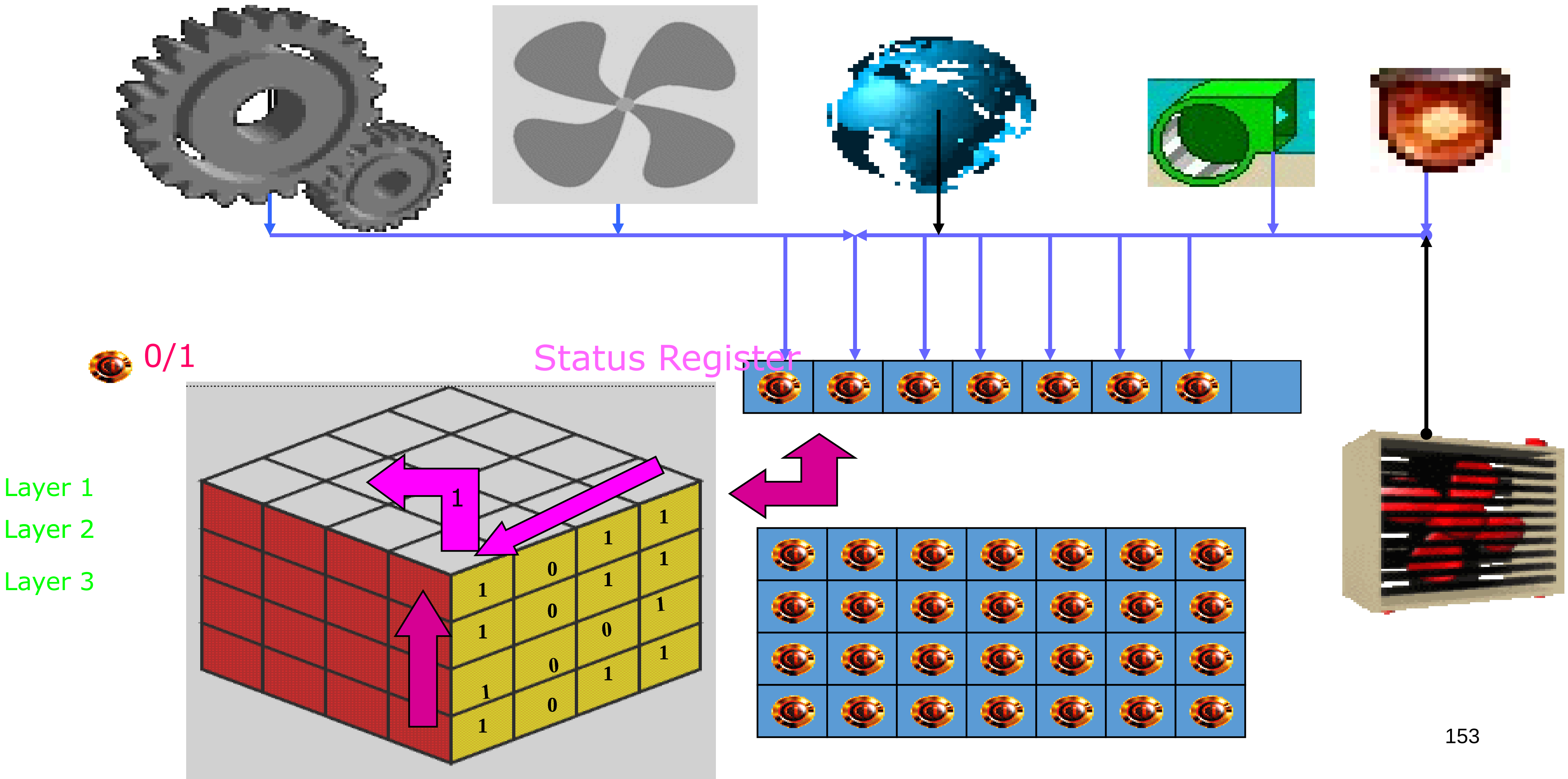


e List
rtment
er Plant
nbers Lounge
nbers Lounge - AHU1
nbers Lounge - AHU2
nbers Lounge - AHU3
Refresh Page
<- Back
Conections
Help
About
Chiller Plant - Country Club
19
17
15
13
11
9
7
5
(5,0)
10 30 50 70 90
X-Axis = Last 90 samples
Y-Axis
CHW RETURN
CHW SUPPLY
12.0 C
7.5 C
CHW 1
OFF
NORMAL
CHW 2
ON
ALARM
CHW 3
OFF
NORMAL
CHILLER 1
0%
OFF
CHILLER 2
80%
ON
CT 1
ON
NORMAL
CT 2
OFF
NORMAL
COW OUT
COW IN
34.0 C
25.5 C
COW 1
OFF
NORMAL
COW 2
OFF
NORMAL
COW 3
ON
NORMAL



e List
rtment
er Plant
nbers Lounge
nbers Lounge - AHU1
nbers Lounge - AHU2
nbers Lounge - AHU3
Refresh Page
<- Back
Conections
Help
About
Members Lounge - AHU 1
AHU CONTROL
ON
ROOM TEMPERATURE
22.1 C
SET POINT (°C)
23
22.5 C
AHU RETURN AIR
16.0 C
OUTDOOR AIR
AHU SUPPLY AIR
FILTER STATUS
NORMAL
VALVE POS.
45.0 %
OUTDOOR TEMPERATURE

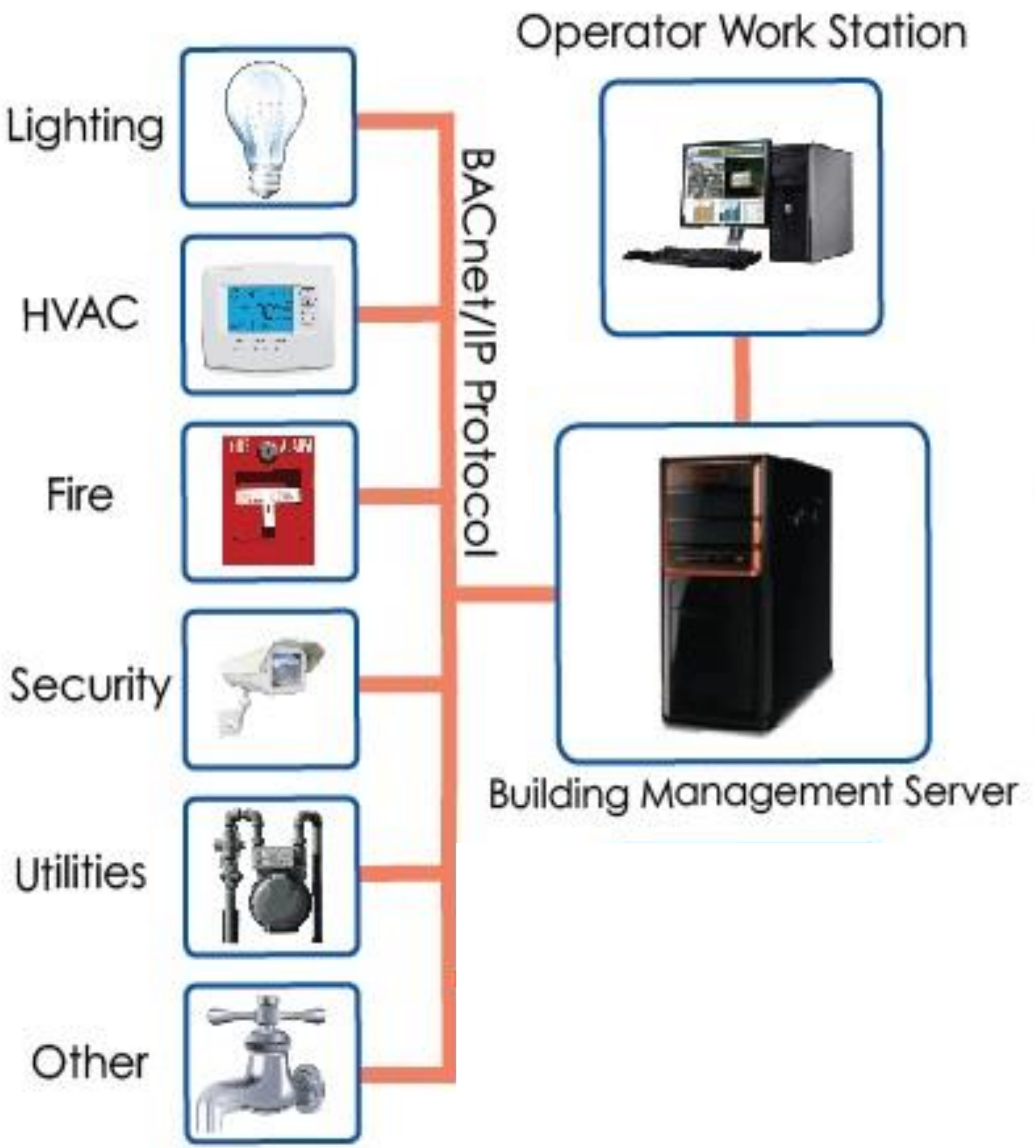
Fail Status Processing



Interoperability

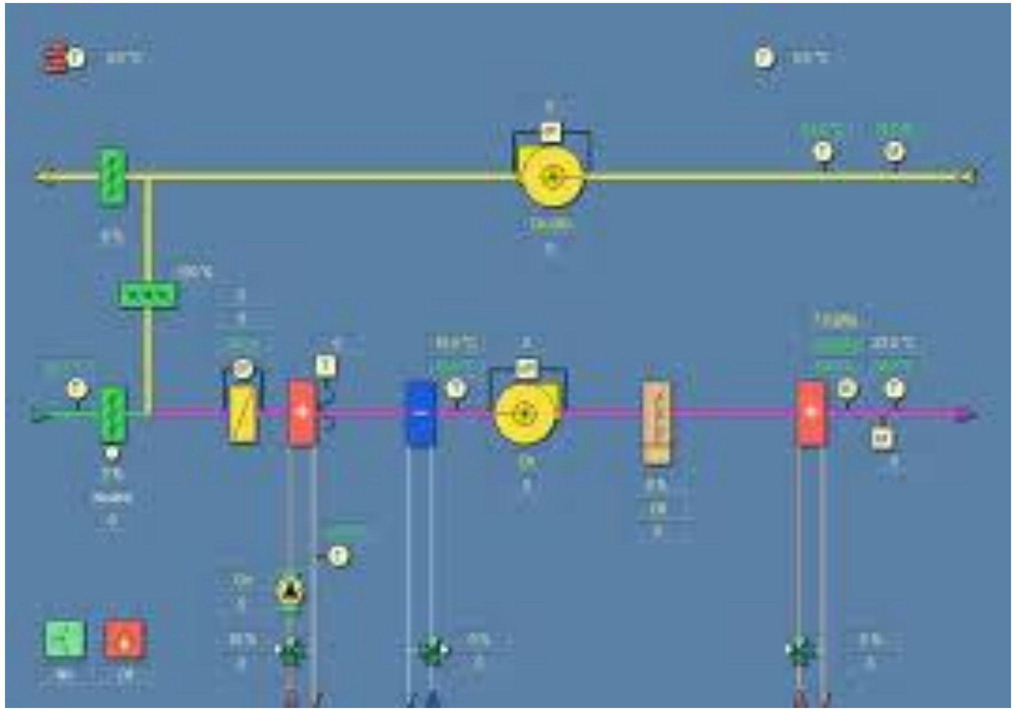
Protocol Integrators will be used

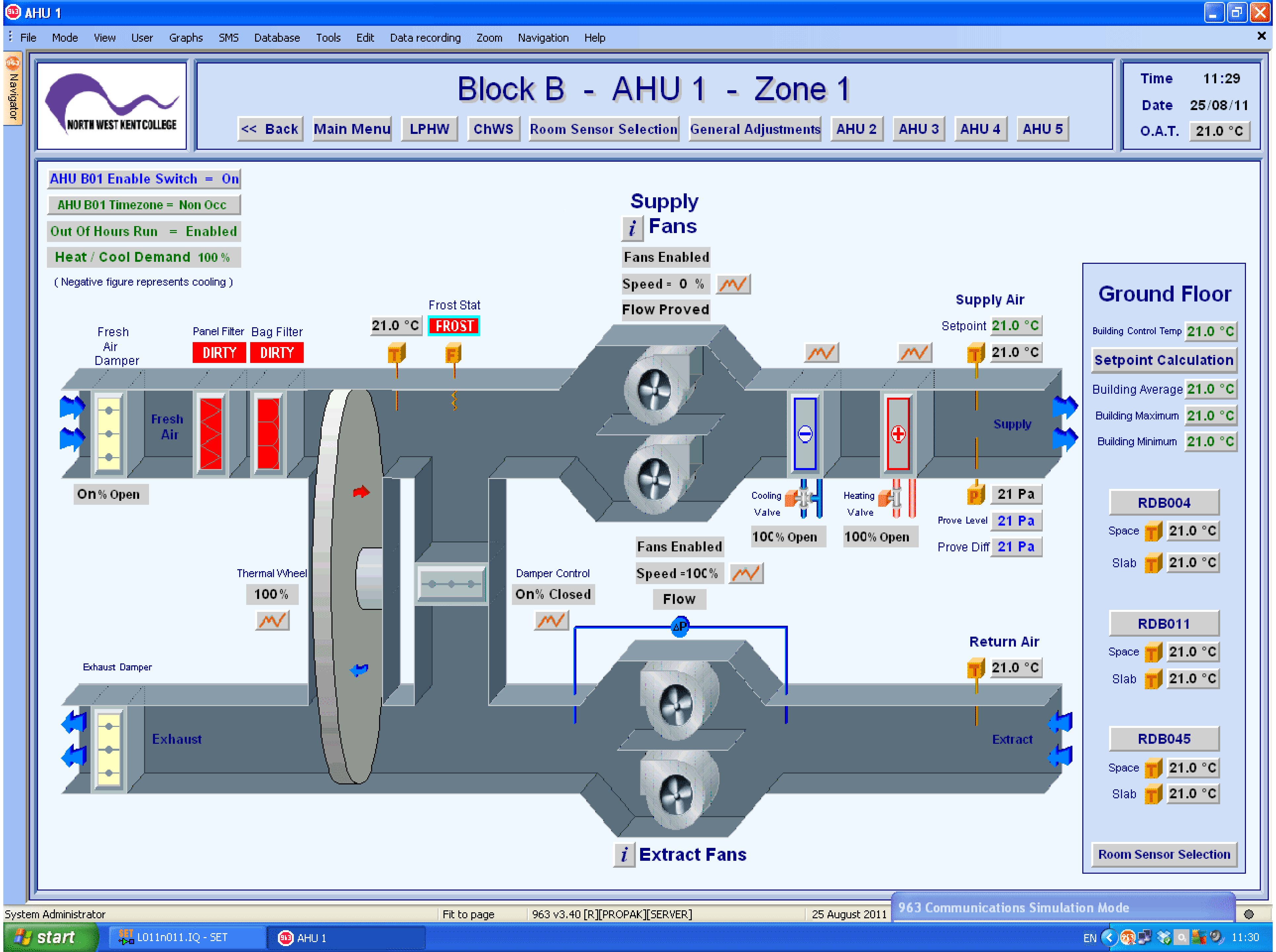
- Generator
- Chillers
- Boilers
- Lift/ escalator
- Lighting system
- Fire Alarm System
- Access Control System
- Software points Number must be known



Software used in BMS

- Sensor – Calibration and configuration software
- Equipment Commissioning Software - VAV
- DDC – Programming software , simulation software , Programs, communication software
- Management Level – BMS software , Database Software , Graphic creating sw, Data representation SW – Excel,




AHU 1
File Mode View User Graphs SMS Database Tools Edit Data recording Zoom Navigation Help
Navigator
NORTH WEST KENT COLLEGE
Block B - AHU 1 - Zone 1
<< Back
Main Menu
LPHW
ChWS
Room Sensor Selection
General Adjustments
AHU 2
AHU 3
AHU 4
AHU 5
Time 11:29
Date 25/08/11
O.A.T. 21.0 °C
AHU B01 Enable Switch = On
AHU B01 Timezone = Non Occ
Out Of Hours Run = Enabled
Heat / Cool Demand 100 %
(Negative figure represents cooling)
Supply Fans
Fans Enabled
Speed = 0 %
Flow Proved
Frost Stat
21.0 °C
FROST
Fresh Air Damper
Panel Filter
Bag Filter
DIRTY
DIRTY
Fresh Air
On % Open
Supply Air
Setpoint 21.0 °C
21.0 °C
Supply
Cooling Valve
Heating Valve
100% Open
100% Open
21 Pa
Prove Level 21 Pa
Prove Diff 21 Pa
Fans Enabled
Speed =100%
Flow
Thermal Wheel
100 %
Damper Control
On % Closed
Exhaust Damper
Exhaust
Return Air
21.0 °C
Extract
Extract Fans
Ground Floor
Building Control Temp 21.0 °C
Setpoint Calculation
Building Average 21.0 °C
Building Maximum 21.0 °C
Building Minimum 21.0 °C
RDB004
Space 21.0 °C
Slab 21.0 °C
RDB011
Space 21.0 °C
Slab 21.0 °C
RDB045
Space 21.0 °C
Slab 21.0 °C
Room Sensor Selection
System Administrator
Fit to page
963 v3.40 [R][PROPAK][SERVER]
25 August 2011
963 Communications Simulation Mode
start
L011n011.IQ - SET
AHU 1
EN
11:30

Programing Software & Program