SCOS-2000
ESA's Spacecraft Control for the 21st Century

Presentation to GSAW 2003

4th – 6th March 2003

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Overview

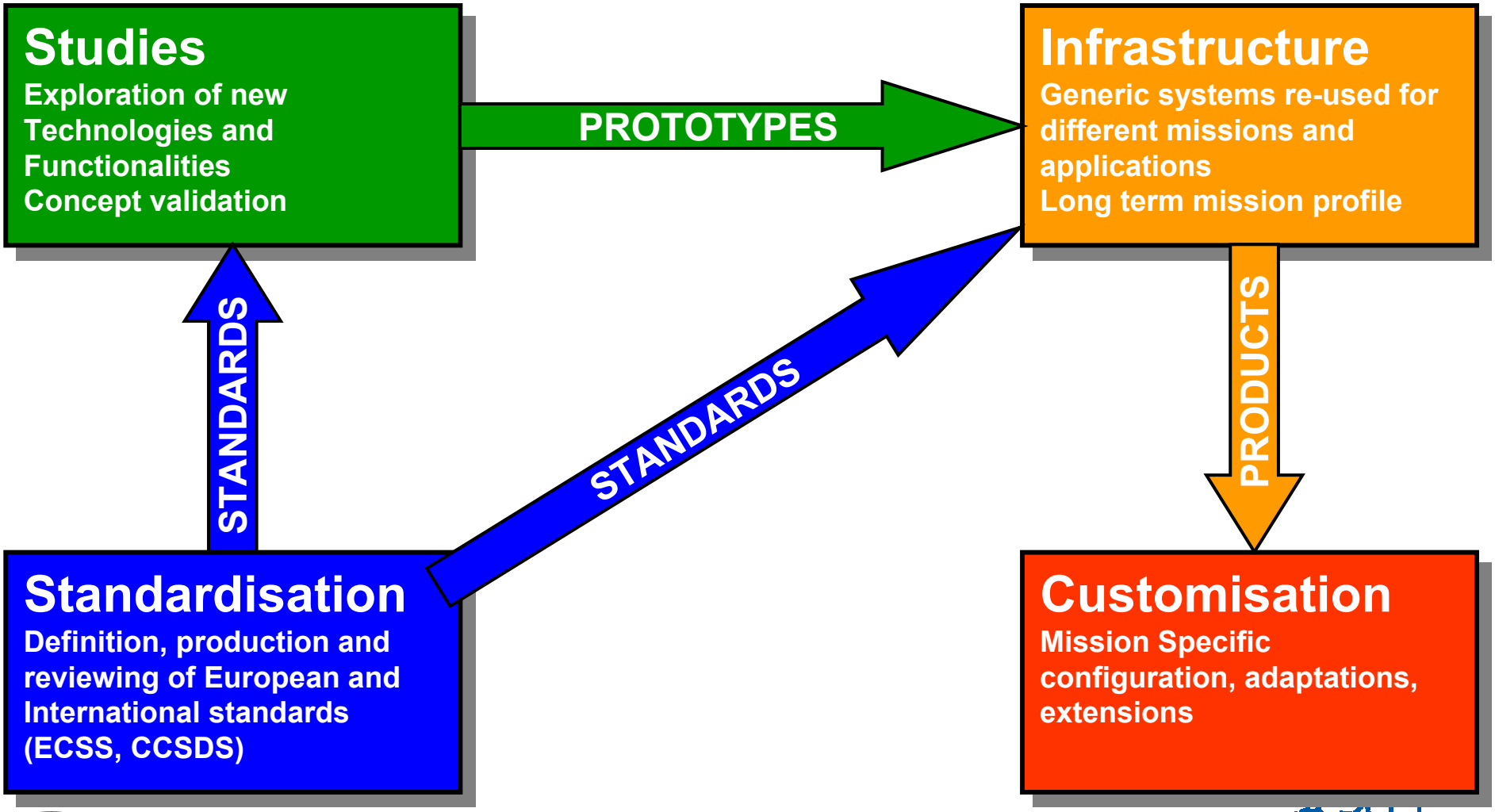
- ESA Objectives, Working Plan and Challenges
- ESA Mission characteristics
- ESA Product Line
- History of ESA Control Systems
- SCOS-2000 in a Ground Segment Context
- SCOS-2000 Client missions and versions
- SCOS-2000 Architectural Concepts
- Lessons learned
- A vision for the future

ESA Objectives

- **Produce re-usable infrastructure (i.e. SW) system components**
  - State of the art technology to allow an effective evolution path
  - System designed to be used for any class of orbits
    - Low orbiting missions
    - Geostationary missions
    - Deep space missions
  - For any class of missions
    - Application missions
    - Scientific missions
    - Earth Observation missions
  - Advanced functionally geared towards a single operation concept / methodology
  - Re-use of same system whenever and wherever possible
    - MCS, EGSE, Station Control
- **Customise existing infrastructure components to meet mission specific needs**
  - Cost effective and fast deployment of a ground segment

THIS HAS BEEN ESA's PRACTICE DURING THE LAST 25 YEARS

ESA working methodology



The challenges

- **In the area of software**
- **Software becomes an increasing element of the ground segment and is a major cost driver**
- **Harmonisation on software technologies**
  - Platforms and OS
  - Languages
  - Standards (e.g. for interface)
- **Harmonisation on software methodologies**
  - Methodology (O-O)
  - Development and test tools
  - Project control and documentation (ECSS-E40)

Product Line

- ESA has introduced many years ago the notion of operational software.
- ESA retains the full ownership on this category of software.
- However the ESA software license regulation allows any ESA member state company to get the license free-of-charge for any ESA operational software.
- This license of course is non-exclusive, cannot be sold, and has to be used only for peaceful purposes.
- Nevertheless it allows those companies to use this software in any offer (even on the world-wide market).
- Business is not made with this software, but rather with the services that can be provided using this software.
- It is a way for ESA to help the European industry to be more competitive.

Product Line

- This is pretty similar to the Open Source concept (with the restriction that it applies only to Europe).
- ESA is the "gatekeeper" of the software, retains the Intellectual Property Rights (IPR), and encourages any European company to use this software.
- It is operationally proven and benefits of many years of experience in operating different classes of missions and of successful MCS engineering.
- ESA is committed to keep this software alive for many years.
- Thus any company using it, may benefit from its further releases, which will include new functionalities as a result of a continuing study program.
- It is certainly more advantageous for a company to follow this line, rather than deriving its own product (which is also legally possible).
- Companies may also make improvements to the software, in which case the preferred approach is that they make them available to ESA, as candidate for inclusion in the product – this is in line with the Open Source approach.

Our best Product : SCOS-2000 ; 54 Licenses in 3 years

ESA Missions Characteristics

- **Geostationary / Geosynchronous**
  - Continuous visibility from single ground station
  - Constant altitude (36,000 Km)
  - Station keeping manoeuvres
  - High bandwidth
  - Uses: Telecommunications, Meteorological (Meteosat)
- **Low earth orbit (RT and Store / Forward –L1, L2-)**
  - Elliptical orbit
  - Limited visibility at ground stations
  - Data stored on board, and dumped when station visible
  - High bandwidth and data rates
  - demanding mission planning requirements
  - Uses: Science missions, earth observation
- **Deep space**
  - Limited visibility
  - Propagation delay (TM/TC)
  - Lower bandwidth
  - Long life, long periods of inactivity
  - Uses: Science missions

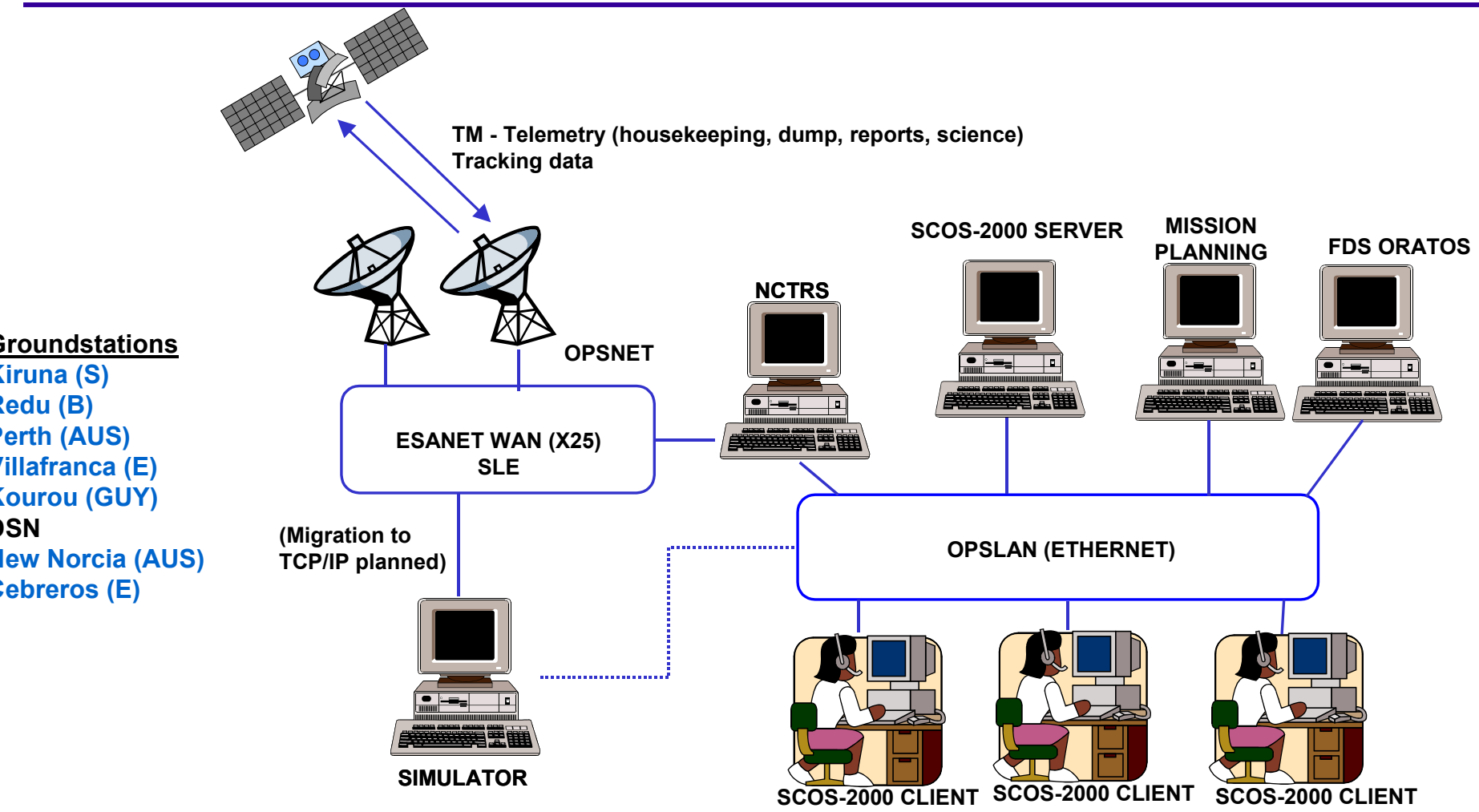
History of ESA control systems

- **MSSS - 1984-1996**
  - Centralised processing, monolithic applications supporting many spacecrafts of different types
  - Frame telemetry / telecommand processing
  - FORTRAN / Assembler
- **SCOS-I - Since 1989**
  - Centralised processing, original architecture based on MSSS (but one S/C per system)
  - Packet telemetry
  - No generic telecommand chain
  - FORTRAN / VMS
- **SCOS-II - 1995-1999 : superceded by SCOS-2000**
  - Distributed processing, new architecture
  - Packet telemetry
  - Generic telecommand chain incorporated
  - C++ / UNIX

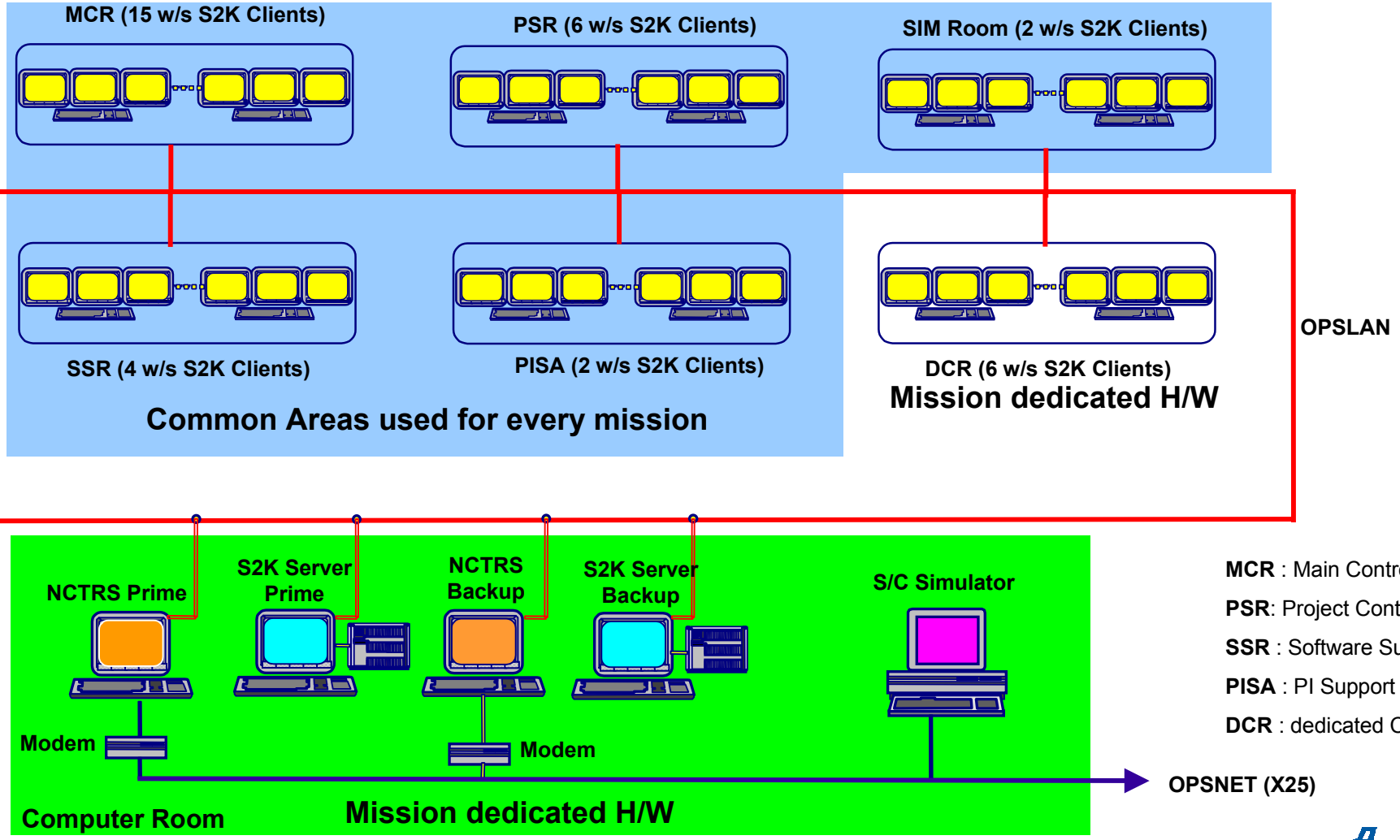
Characteristics of a good MCS : ESA's view

- **The characteristics of a good Mission Control System to be used as generic infrastructure are as follows:**
  - must be generic,
    - designed to serve wide range of missions,
    - customisable: easily adapted or extended,
  - must be open i.e. must have well defined interfaces,
  - should be well documented and easy to install and configure,
  - being able to run on popular platforms, avoiding as far as possible tie-in to one particular platform vendor;
  - minimising dependence on commercial off the shelf (COTS) software,
  - should have long-term support commitment from the supplier of the product,
  - should have product expertise available on competitive market, i.e. potential users are not locked into one provider of support;
  - can be easily distributed to potential users or "clients" i.e. **distribution is not blocked by issues of Intellectual Property Rights or licensing**;
- **All these issues have been considered when implementing SCOS-2000.**

Complete system overview



Spacecraft control systems - LEOP system



MCR : Main Control Room

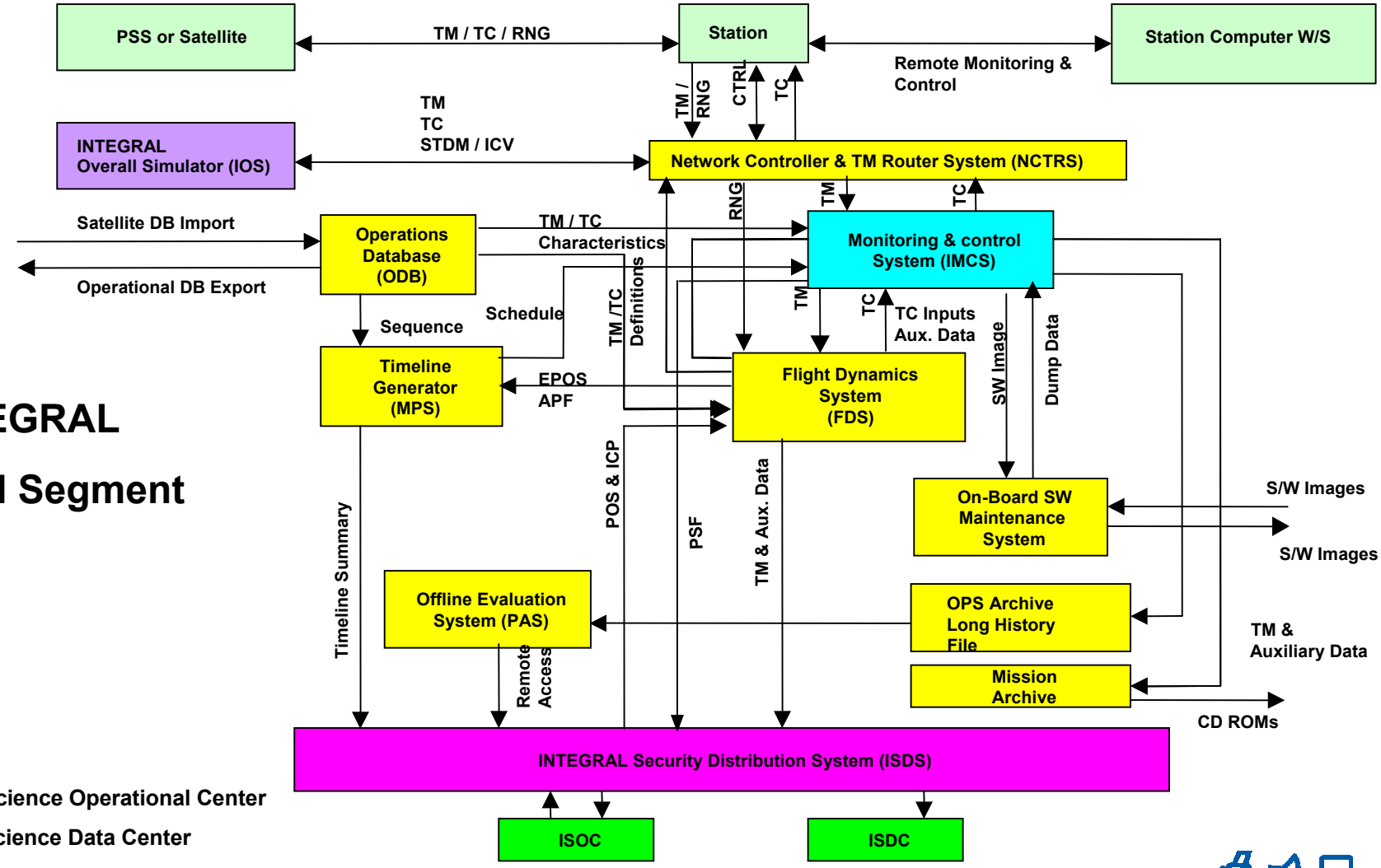
PSR: Project Control Room

SSR : Software Support Room

PISA : PI Support Area

DCR : dedicated Control Room

An S2K based MCS in a GS Context



OC: Integral Science Operational Center

DC: Integral Science Data Center

S2K Client missions

- **ESA**
  - **Existing or completed**:
    - SOHO – NASA Goddard, USA.
    - TEAMSAT - Experimental satellite
    - MTP – EUMETSAT
    - HUYGENS - Interfaces via NASA system at JPL, California.
    - PROBA - experimental satellite,
    - MSG - Meteosat Second Generation LEOP system.
    - INTEGRAL - International Gamma Ray Laboratory.
  - **Development ongoing:**
    - ROSETTA MCS - 10 year mission, launch 2004
    - Mars Express MCS - Mars exploration, launch 2003
    - SMART-1 MCS - experimental propulsion, launch 2003
    - Venus Express MCS
    - Cryosat MCS– First ESA mission on evolution platform
    - GOCE MCS
    - ADM MCS
    - Herschel / Planck MCS
    - ESA Vega Launcher EGSE (in evaluation)
    - Herschel / Planck Central Checkout System (EGSE) (Red Hat 7.2)
    - Galileo MCS (34 satellites) (in evaluation)

S2K Client missions

- **External Users**
  - Canada
    - Radarsat 2
    - Telecommunication Satellites (under evaluation)
  - German Space Agency DLR-GSOC
    - GRACE
    - BIRD
  - Eutelsat
    - New MCS system – NEO
  - Italian Space Agency – ASI
    - Cosmos Skynet
  - Itallian Aeronautical research Centre
    - USV (unmanned Space Vehicle)
  - 20 European Scientific Institutes
    - Herschel / Planck Instrument EGSE (SUSE 7.3)
  - Japan
    - Telecommunication Satellites (under evaluation)

SCOS-2000 Versions

- **Classic**
  - Sun Hardware
  - Solaris 2.6
  - Costly COTS (Object Store, Orbix)
  - Culminates in version 2.4.1
- **Evolution (Release 2.1.e, 2.3.e)**
  - PC Hardware (HP, Dell..)
  - LINUX (SUSE 7.3) or Solaris 2.6
  - Open Source COTS (POST, OmniOrb)
- **Release 3.0 January 2003**
  - Classic + Evolution lines merged
  - Solaris 8
  - Archive Upgrades
- **Release 3.1 September 2003**
  - Linuxs OS migration to version SUSE 8.1 Professional
  - MMI migration to ILOG views vers. 5.0
  - Integration of upgrades done by different missions
- **Release 4.0 June 2004**
  - Multi-Mission (constellation, formation flying) (LEO, Geo, Deep Space)
  - Full EGSE compliant

SCOS-2000 Architecture concepts

- **SCOS-2000 is a mission control system kernel**
  - with commonality for spacecraft check-out systems and S/C software validation facilities
- **SCOS-2000 is a set of object oriented components**
  - allows re-use by system developers
- **SCOS-2000 is a set of generic executables**
  - may be used ‘as-is’ if functionality matches needs of users
  - provides basis and examples for client mission developers
  - allows generic functionality to be validated
- **SCOS-2000 provides mechanisms for handling the functionality of spacecraft control and checkout control systems**
- **SCOS-2000 can be extended to cover functionality required by specific missions**
- **SCOS-2000 is a distributed and scalable system**
- **SCOS-2000 must be a configurable and open system**

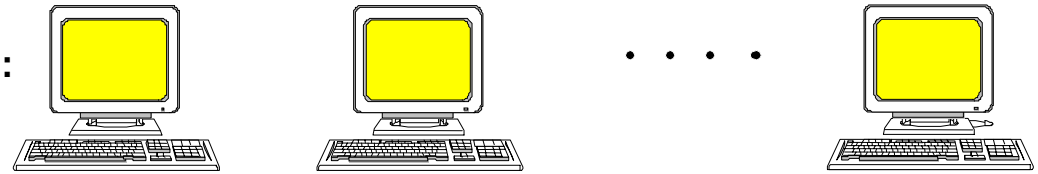
SCOS-2000 Enabling Technology

- **Object Oriented Analysis & Design**
  - Rational Rose (UML)
- **Unix, C++, STL**
- **COTS:**
  - ILOG views - GUI library
  - Ctree+ (packet archive)
  - ObjectStore [SCOS-2000 Classic)
  - Iona ORBIX (CORBA 2.1) [SCOS-2000 Classic]
  - OmniORB (fully CORBA 2.3 compliant) [SCOS-2000 Evolution]
  - POST++ [SCOS-2000 Evolution]
- **Public Domain:**
  - Flex, Bison (for OL parsing)
  - Tcl/Tk (old launcher - now not used)
  - a2ps (for postscript output printouts)
  - zlib (for packet compression)
- **Documentation:**
  - MS-Word
  - GEORGE (HTML)

- **Space Standards**
  - CCSDS standards for Packet Telemetry and Telecommands.
  - ECSS Packet Utilisation Standards, a standard which defines the different packet typesand sub-types in a systematic way, grouping them into a number of “services” that are offered between space and the ground.
- **SLE**
  - It is also possible to offer a suite of Ground Station Interface Software that is conformant to the Space Link Extension (SLE)standard, an CCSDS standard to allow more ready interoperability of ground stations between different operators.

SCOS-2000 Client / Server

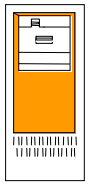
CLIENTS:



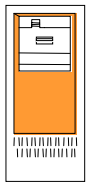
Client MMI Applications
- Desktop (alarm display)
- Monitoring Display Container (TM)
- OOL Display (TM)
- Event Logger (EV)
- Manual/Auto Stacks (TC)
- TC History (TC)
- Caches (TM/TC/EV)
- Configuration client (TM/TC Spacon)

SERVERS:

Backup server

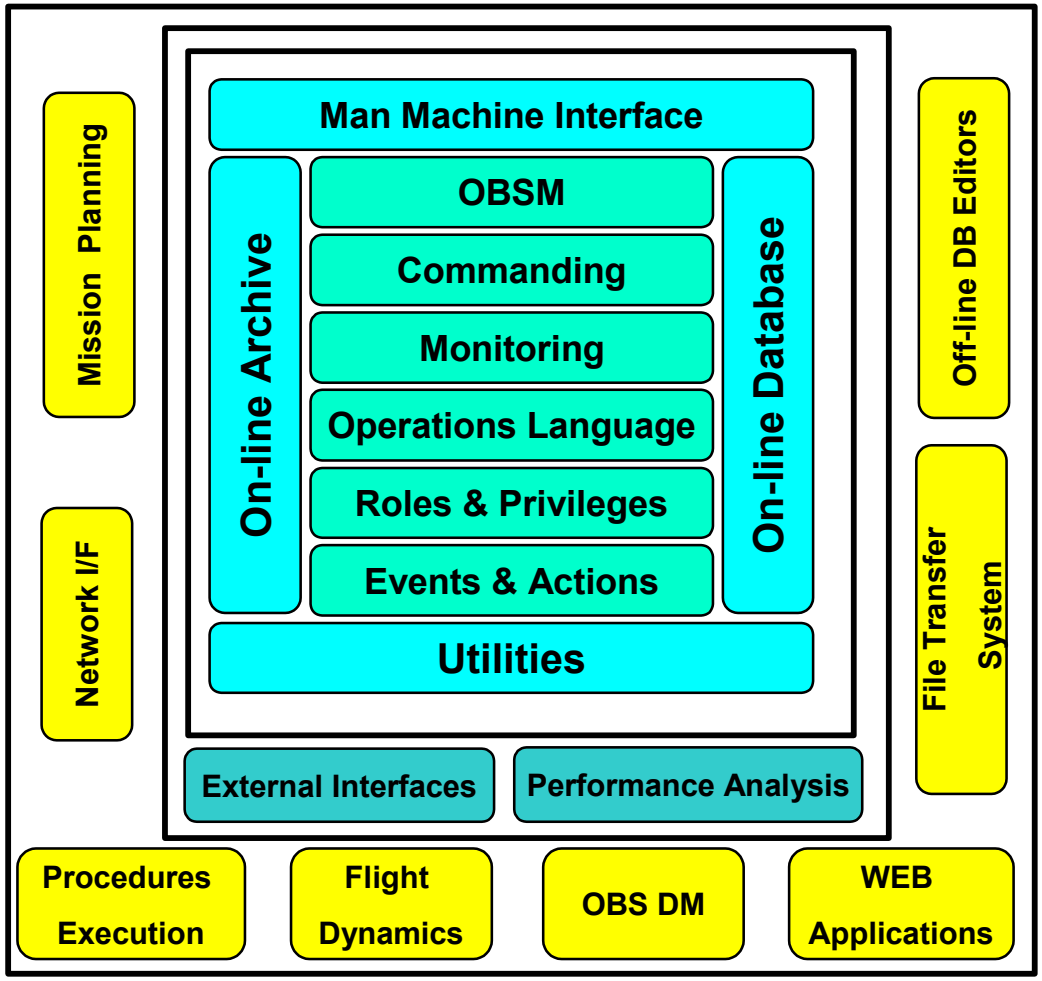


Prime server

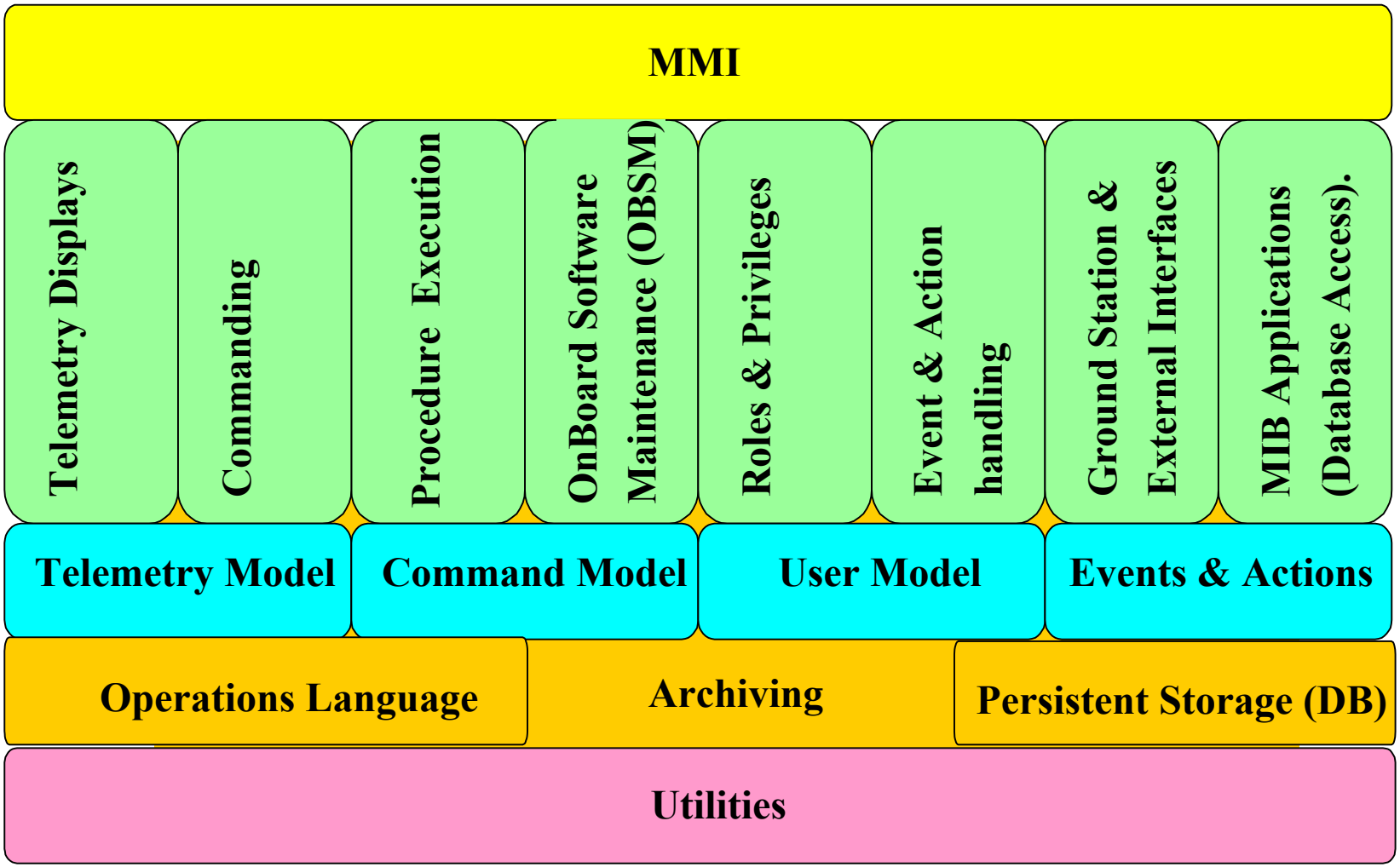


Server Processes
- Packetiser (TM)
- Behaviour (Limits) checker (TM)
- Synthetic parameter packet generator (TM)
- Multiplexer, Releaser, Verifier, OBQM (TC)
- Archive (TM/TC/EV)
- Events & Actions Servers (EV)
- Configuration (MISCdynamic) server

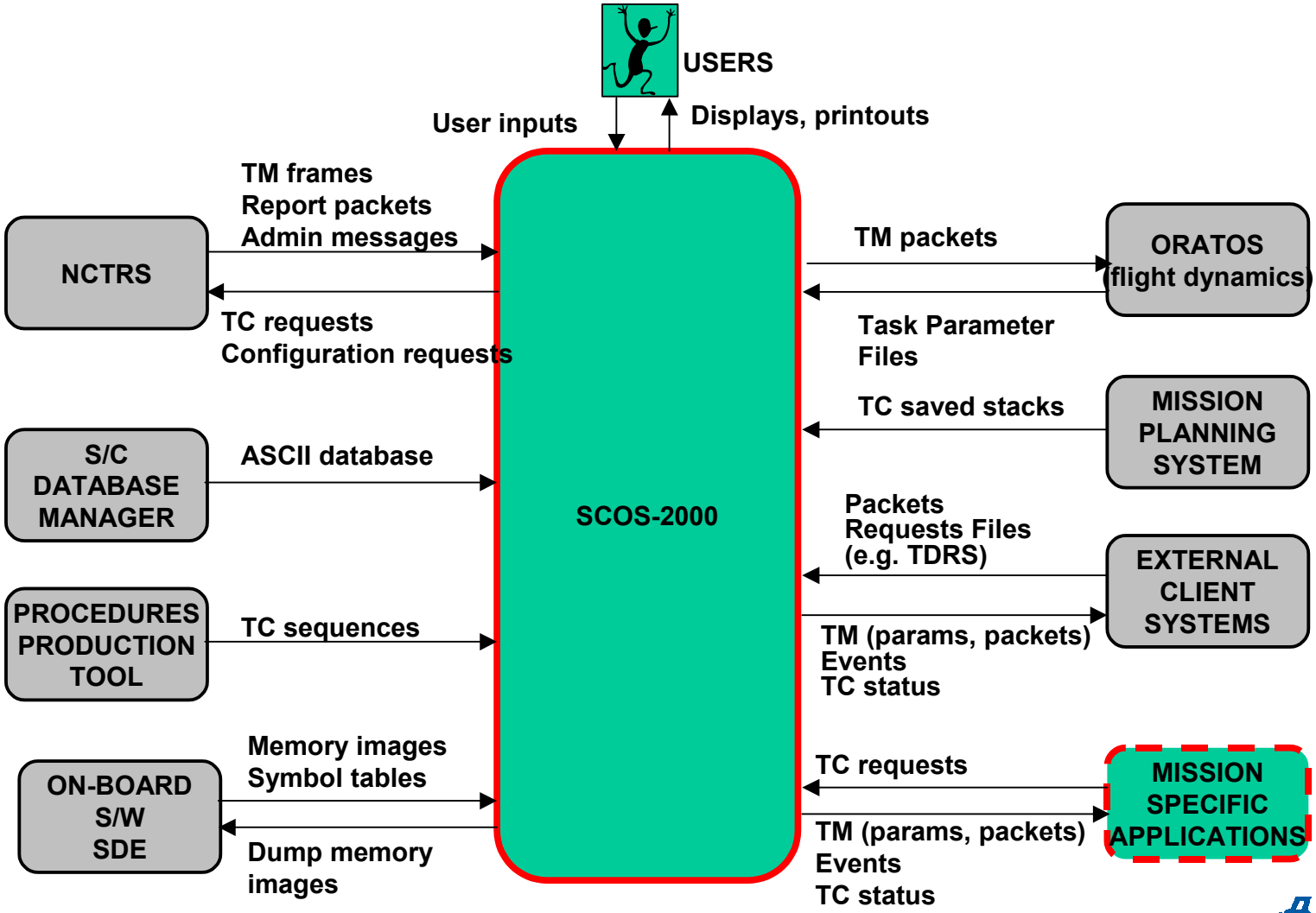
SCOS-2000 Architecture Context



SCOS-2000 Software Layers



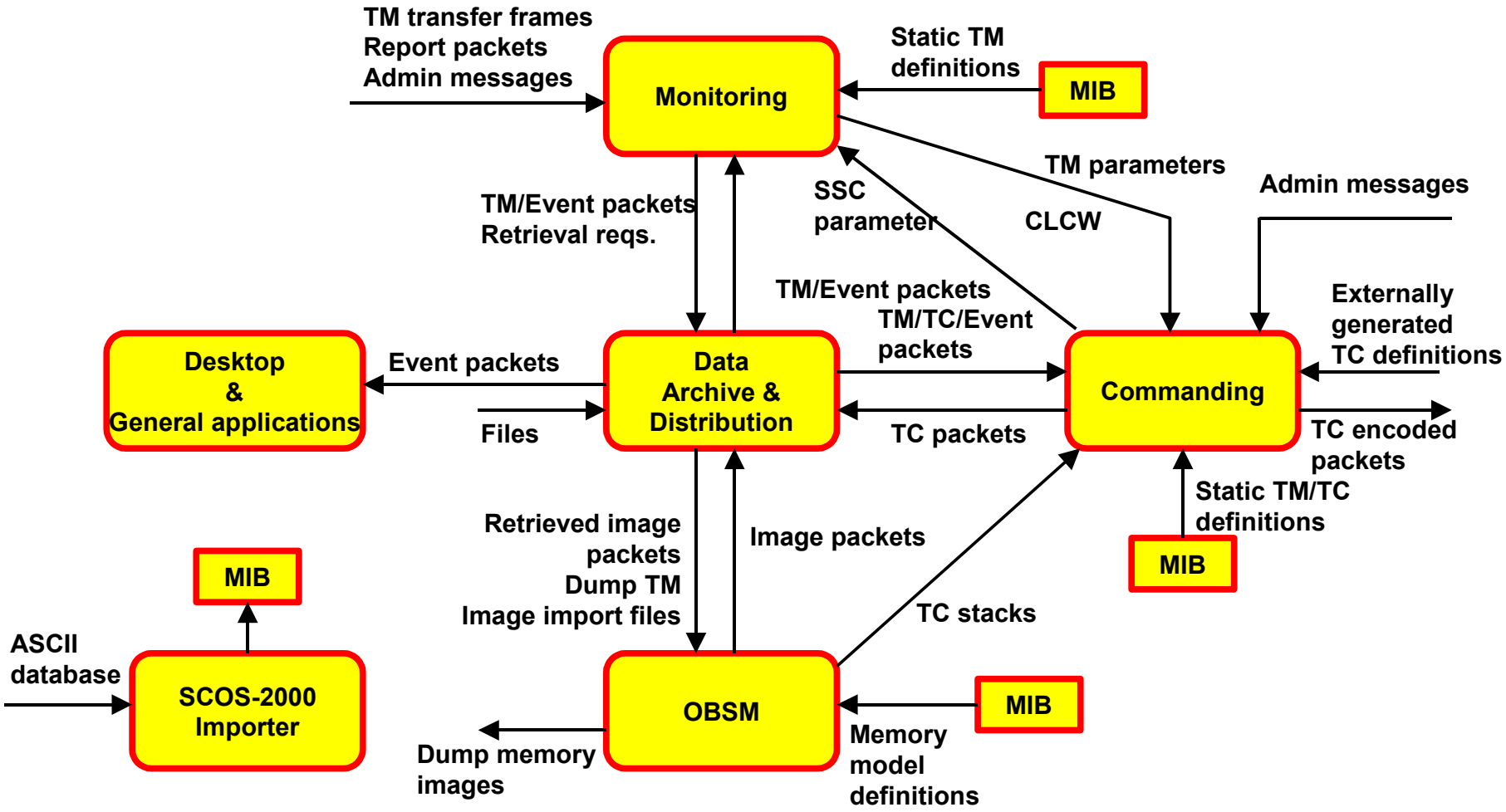
SCOS-2000 System Overview



System interfaces

- **Users**
  - Client system developers
  - End users
- **NCTRS - Network Command, Telemetry & Ranging System**
  - TMP4, TCE, MKII, MPTS MKIII, STC II
- **Database**
  - S/C database
  - Database editing tool
- **FOP PRODUCTION TOOL**
  - command sequences (imported into MIB)
- **OBSM SDE**
  - OBSM image files (received, exported)
- **Flight dynamics (ORATOS)**
  - TM packets (real-time, retrieved)
  - Task parameter file (TPF)
- **Mission planning system**
  - Command schedules
- **Mission-specific MCS applications**
  - APIs
  - low-level services
- **External systems (e.g. procedure execution systems)**
  - packet
  - parameter
  - command
  - event

Top level components



Commanding functions

- **Manual Stack**
  - **Load Commands**
    - Command encoding
    - Commands with parameters
    - Parameter de-calibration
    - Execution time-tagged
  - **Release Dependencies**
    - Grouping
    - Blocking
    - Delta release times
    - Interlocking
  - **Master Manual Mode**
  - **Wait Mode**
  - **Static/Dynamic PTV**
  - **Load Sequences**
    - Formal sequence parameters
    - Absolute start/execution time
  - **Load/Save**
    - Commands
    - Sequences
    - Stack files
    - TPFs
- **Autostack**
  - Restricted Manual Stack functions
  - No editing
  - Execution/Release based
- **Multiplexer (allowing multiple sources to command in parallel)**
- **Command releaser (interface to external command destination - NCTRS)**
- **On-Board Queue Model (time-tagged commands)**
- **Command verifier (performs multi-stage command verification and status consistency check disabling on affected TM parameters)**
- **On-Board Queue Display (OBQD)**
- **Command History Display**
- **Command Query Display**

Monitoring functions

- **TM Packetiser**
  - Packet reconstruction (from frames)
  - CLCW Extraction
  - Quality checks
  - Continuity/sequence checks
- **Parameter extraction (super-commutation)**
- **Synthetic parameters**
  - OL-synthetic
  - Compiled OL
  - Hard-coded (C++)
  - Re-calculated for retrieved data
- **Parameter processing (calibration) Parameter validity**
- **Behaviour checking**
  - Limits
  - Expected Status
  - Status Consistency
- **Retrievals**
  - Retrieval start from given time
  - Datastream selection
  - Datastream merging (data from up to 4 streams merged on single displays)
- **Configuration**
  - Retrieval rate
  - Processing control (local, global)
  - Distribution via packet
- **Online changes**
  - Limit values
  - Calibration points
  - OL expressions (interpreted)
  - Alphanumeric displays
  - Graphics definitions
  - MIMICS editors

Monitoring functions

- **Displays**
  - Alphanumeric display (AND) - 32 or 64 parameters
  - Graphics (GRD)
    - 1-8 parameter vs. time
    - 1-8 strip chart emulation
    - 1-8 parameter vs. parameter
  - MIMICs
  - Scrolling (SCD)
  - Telemetry Query Display (TQD)
  - Out of limits displays
  - Events
- **Packet Displays**
  - Variable Packet Display
  - Telemetry Packet History Display
  - On-Board Event History Display
- **TM processing control (TM SPACON)**
  - Filing enable/disable
  - Reset status consistency check state
  - Extendable by missions
- **Synthetic parameter packet generator**
  - Allows permanent filing of database defined synthetic parameters

Distribution and filing

- **Centralised filing of all received packets**
  - Non-circular filing (continuous enlargement) using C-Tree+ COTS
  - Files split for long-term archiving
  - Fixed or variable length records
- **Filing according to**
  - Type (TM, TC, Event)
  - SCOS-2000 packet ID (SPID)
  - Datastream (logical grouping of data, e.g. R-T, playback)
  - Time
- **Retrievals independent from real-time packet handling**
- **Distribution of packets to distributed client caches**
  - TCP/IP
- **Global filing enable/disable (from admin tool called PDSadmin)**
- **Hot switch to backup server**
- **HF administration tool (also PDAadmin primarily to be used by S/W support)**
  - delete records, display configuration, dump/export/print packets, re-send packets, splits archive

Lessons learned

- **Production of S/W re-usable infrastructure for all ESA missions controlled from our OCC at Darmstadt, Germany, has been a great success in the last 25 years**
- **Open Source type approach with a licensing free-of-charge policy within Europe is proving to be excellent for our Industry in terms of competitiveness.**
- **European Industry is requesting ESA to enhance this approach to other Ground Segment Data System Infrastructure**

- This has lead us to our new framework

- **EGOS (ESA Ground Operations Software system)**

A vision for the future

- EGOS is a family of products following the same SCOS-2000 approach
  - GSTV: Ground Systems Test and Validation
  - MCCM: Multi-mission Configuration Control Manager
  - GSMC: Ground Systems Monitoring and Control
  - NCTRS / SLE : Network Command and Telemetry Routing System
  - SIMSAT: Simulator Infrastructure
  - GFTS: Generic File Transfer System
  - GDDS: Generic Data Disposition System
  - OPS: Operations Preparation System
  - ADAS: Advanced Data Analysis System
  - APES: Automated Procedure Execution System
  - EVA: ESA Versatile Archive
  - EGSE: Electrical Ground Support Equipment
  - MPS: Mission Planning System
  - TMTCS: TM and TC BaseBand System
  - FDS: Flight Dynamics System