# Switch Fabrics

**Switching Technology S38.165**
**http://www.netlab.hut.fi/opetus/s38165**



## Switch fabrics

- Basic concepts
- Time and space switching
- Two stage switches
- Three stage switches
- Cost criteria
- Multi-stage switches and path search

## Switch fabrics (cont.)

- Multi-point switching
- Self-routing networks
- Sorting networks
- Fabric implementation technologies
- Fault tolerance and reliability



## Basic concepts

- Accessibility
- Blocking
- Complexity
- Scalability
- Reliability
- Throughput

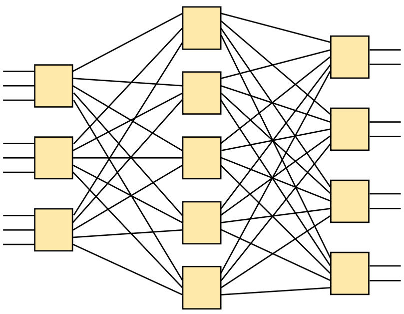
# Accessibility

- A network has **full accessibility (= connectivity)** when each inlet can be connected to each outlet (in case there are no other I/O connections in the network)
- A network has a **limited accessibility** when the above given property does not exist
- Interconnection networks applied in today's switch fabrics usually have full accessibility

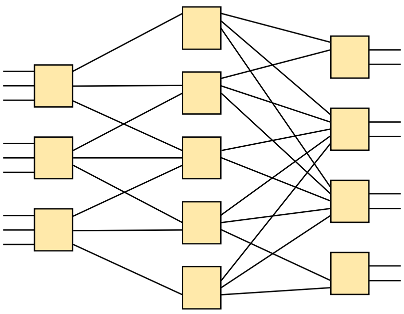


# Accessibility (cont.)

Example of full accessibility



Example of limited accessibility



# Blocking

- Blocking is defined as failure to satisfy a connection request and it depends strongly on the combinatorial properties of the switching networks

<table>
<tr><th>Network class</th><th>Network type</th><th>Network state</th></tr>
<tr><td rowspan="3">Non-blocking</td><td>Strict-sense non-blocking</td><td>Without blocking states</td></tr>
<tr><td>Wide-sense non-blocking</td><td rowspan="3">With blocking state</td></tr>
<tr><td>Rearrangeably non-blocking</td></tr>
<tr><td>Blocking</td><td>Others</td></tr>
</table>



# Blocking (cont.)

- **Non-blocking** - a path between an arbitrary idle inlet and arbitrary idle outlet can always be established independent of network state at set-up time
- **Blocking** - a path between an arbitrary idle inlet and arbitrary idle outlet cannot be established owing to internal congestion due to the already established connections
- **Strict-sense non-blocking** - a path can always be set up between any idle inlet and any idle outlet without disturbing paths already set up
- **Wide-sense non-blocking** - a path can be set up between any idle inlet and any idle outlet without disturbing existing connections, provided that certain rules are followed. These rules prevent network from entering a state for which new connections cannot be made
- **Rearrangeably non-blocking** - when establishing a path between an idle inlet and an idle outlet, paths of existing connections may have to be changed (rearranged) to set up that connection

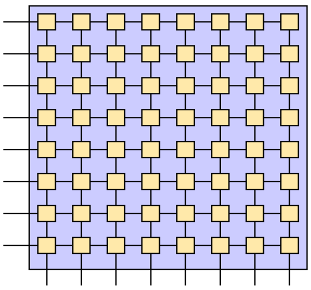
# Complexity

- Complexity of an interconnection network is expressed by **cost index**
- Traditional definition of cost index gives the **number of cross-points in a network**
  - used to be a reasonable measure of space division switching systems
- Nowadays cost index alone does not characterize cost of an interconnection network for broadband applications
  - VLSIs and their integration degree has changed the way how cost of a switch fabric is formed (number of ICs, power consumption)
  - management and control of a switching system has a significant contribution to cost

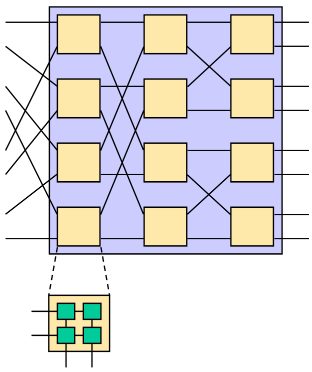


# Complexity (cont.)

Cost index of an 8x8 crossbar is 64 (cross-points)



Cost index of an 8x8 banyan is 12x4= 48 (cross-points)



# Scalability

- Due to constant increase of transport links and data rates on links, scalability of a switching system has become a key parameter in choosing a switch fabric architecture
- Scalability  describes ability of a system to evolve with increasing requirements
- Issues that are usually matter of scalability
  - number of switching nodes
  - number of interconnection links between nodes
  - bandwidth of interconnection links and inlets/outlets
  - throughput of switch fabric
  - buffering requirements
  - number of inlets/outlets supported by switch fabric



# Scalability (cont.)

Example of scalability

- a switching equipment has room for 20 line-cards and the original design supports 10 Mbit/s interfaces (one per line card)
- throughput of switch fabrics is scalable from 500 Mbit/s to 2 Gbit/s
- original switch fabric can support new line cards that implement two 10 Mbit/s interfaces each
- when line interfaces are replaced with 100 Mbit/s rates (one per line-card), the switch fabric has to be updated (scaled up) to 2 Gbit/s speed
- buffering memories need to be replaced by faster (and possible larger) ones
- larger number of line cards implies at least new physical design
- increase of line rates beyond 100 Mbit/s means redesign of switch fabric

# Reliability

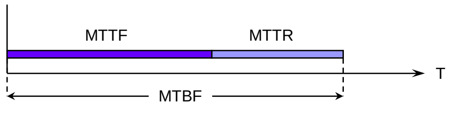
- Reliability and fault tolerance are system measures that have an impact on all functions of a switching system
- Reliability defines probability that a system does not fail within a given time interval provided that it functions correctly at the start of the interval
- Availability defines probability that a system will function at a given time instant
- Fault tolerance is the capability of a system to continue its intended function in spite of having a fault(s)
- Reliability measures:
  - MTTF (Mean Time To Failure)
  - MTTR (Mean Time To Repair)
  - MTBF (Mean Time Between Failures)



# Reliability (cont.)

Relation of reliability R(t) to availability F(t) is given by
F(t) = 1 – R(t)

Relation of MTTF, MTTR and MTBF



## Throughput

- Throughput gives forwarding/switching speed/efficiency of a switch fabric
- It is measured in bits/s, octets/s, cells/s, packet/s, etc.
- Quite often throughput is given in the range (0 ... 1.0], i.e. the obtained forwarding speed is normalized to the theoretical maximum throughput



## Switch fabrics

- Basic concepts
- **Time and space switching**
- Two stage switches
- Three stage switches
- Cost criteria
- Multi-stage switches and path search

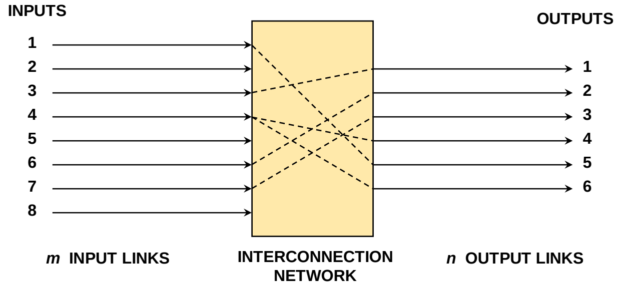
# Switching mechanisms

- A switched connection requires a mechanism that attaches the right information streams to each other
- Switching takes place in the switch fabric, the structure of which depends on network's mode of operation, available technology and required capacity
- Communicating terminals may use different physical links and different time-slots, so there is an obvious need to switch both in time and in space domain
- **Time and space** switching are basic functions of a switch fabric



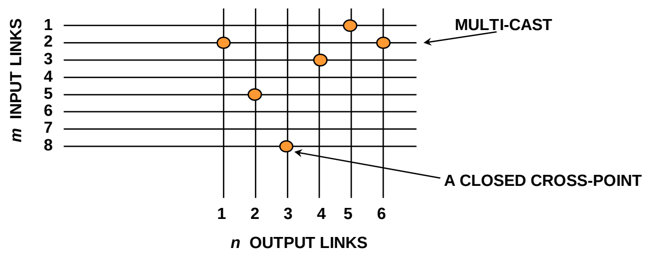
# Space division switching

- A space switch directs traffic from input links to output links
- An input may set up one connection (1, 3, 6 and 7), multiple connections (4) or no connection (2, 5 and 8)



# Crossbar switch matrix

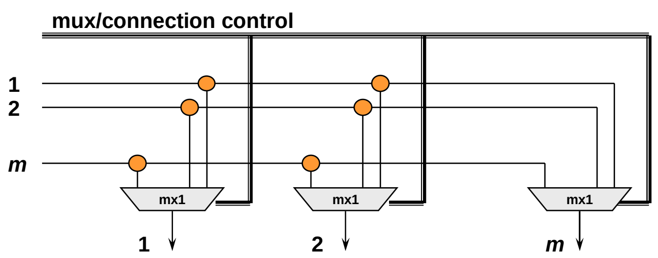
- Crossbar matrix introduces the basic structure of a space switch
- Information flows are controlled (switched) by opening and closing cross-points
- ***m*** inputs and ***n*** outputs => ***mn*** cross-points (connection points)
- Only one input can be connected to an output at a time, but an input can be connected to multiple outputs (multi-cast) at a time





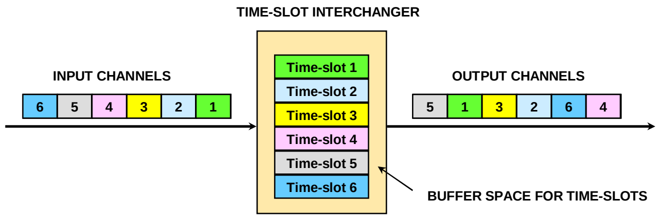

# An example space switch

- *m* x1 -multiplexer used to implement a space switch
- Every input is fed to every output mux and mux control signals are used to select which input signal is connected through each mux



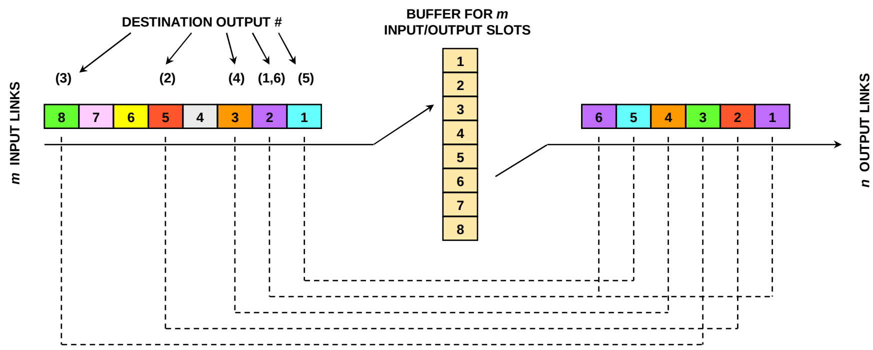
# Time division multiplexing

- Time-slot interchanger is a device, which buffers *m* incoming time-slots, e.g. 30 time-slots of an E1 frame, arranges new transmit order and transmits *n* time-slots
- Time-slots are stored in buffer memory usually in the order they arrive or in the order they leave the switch - additional control logic is needed to decide respective output order or the memory slot where an input slot is stored



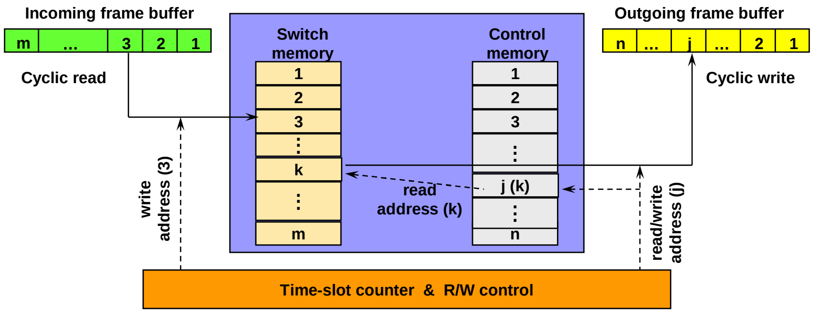



# Time-slot interchange



# Time switch implementation  example 1

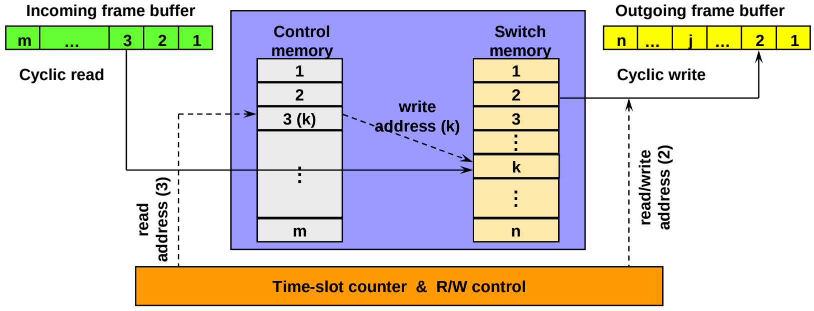
- Incoming time-slots are written cyclically into switch memory
- Output logic reads cyclically control memory, which contains a pointer for each output time-slot
- Pointer indicates which input time-slot to insert into each output time-slot






# Time switch implementation  example 2

- Incoming time-slots are written into switch memory by using write-addresses read from control memory
- A write address points to an output slot to which the input slot is addressed
- Output time-slots are read cyclically from switch memory



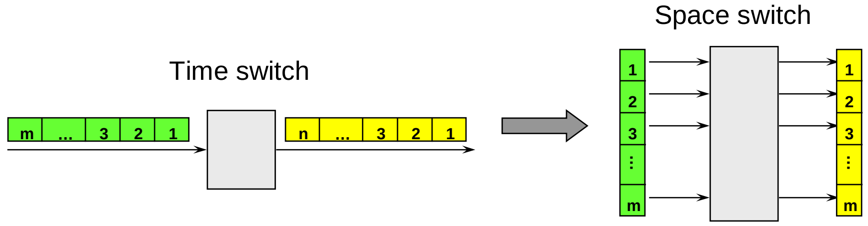
# Properties of time switches

- Input and output frame buffers are read and written at wire-speed, i.e. *m* R/Ws for input and *n* R/Ws for output
- Interchange buffer (switch memory) serves all inputs and outputs and thus it is read and written at the aggregate speed of all inputs and outputs
  => speed of an interchange buffer is a critical parameter in time switches and limits performance of a switch
- Memory speed requirement can be cut by utilizing parallel to serial conversion
- Speed requirement of control memory is half of that of switch memory (in fact a little moor than that to allow new control data to be updated)



# Time-Space analogy

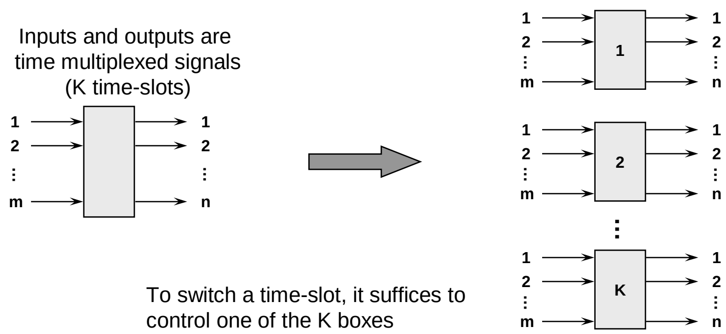
- A time switch can be logically converted into a space switch by setting time-slot buffers into vertical position => time-slots can be considered to correspond to input/output links of a space switch
- But is this logical conversion fair ?



# Space-Space analogy

- A space switch carrying time multiplexed input and output signals can be logically converted into a pure space switch (without cyclic control) by distributing each time-slot into its own space switch

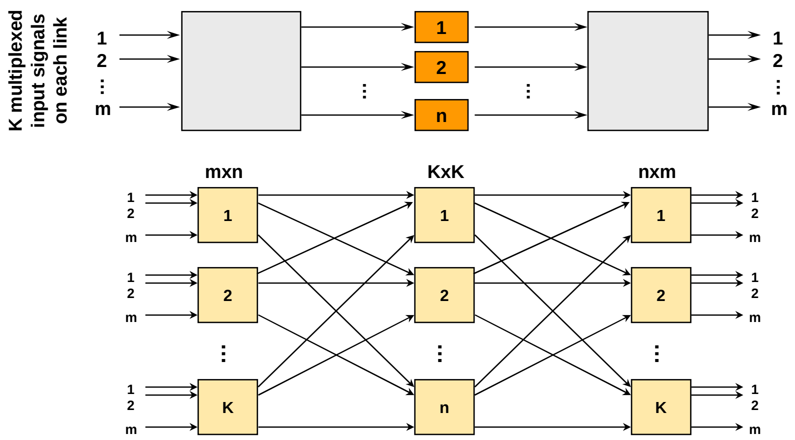
Inputs and outputs are time multiplexed signals (K time-slots)




To switch a time-slot, it suffices to control one of the K boxes



# An example conversion



## Properties of space and time switches

**Space switches**

- number of cross-points (e.g. AND-gates)
  - $m$ input x $n$ output = $mn$
  - when $m=n$ => $n^2$
- output bit rate determines the speed requirement for the switch components
- both input and output lines deploy “bus” structure
  => fault location difficult

**Time switches**

- size of switch memory (SM) and control memory (CM) grows linearly as long as memory speed is sufficient, i.e. SM + CM + input buffering + output buffering
  = 2 x 2 x number of time-slots
- a simple and cost effective structure when memory speed is sufficient
- speed of available memory determines the maximum switching capacity



## Switch fabrics

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- **Two stage switches**
- Three stage switches
- Cost criteria
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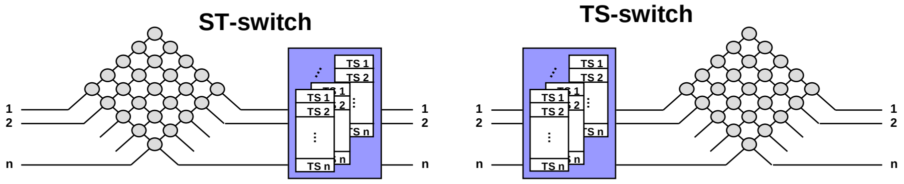
# A switch fabric as a combination of space and time switches

- Two stage switches
  - Time-Time (TT) switch
  - Time-Space (TS) switch
  - Space-Time (ST) switch
  - Space-Space (SS) switch
- TT-switch gives no advantage compared to a single stage T-switch
- SS-switch increases blocking probability



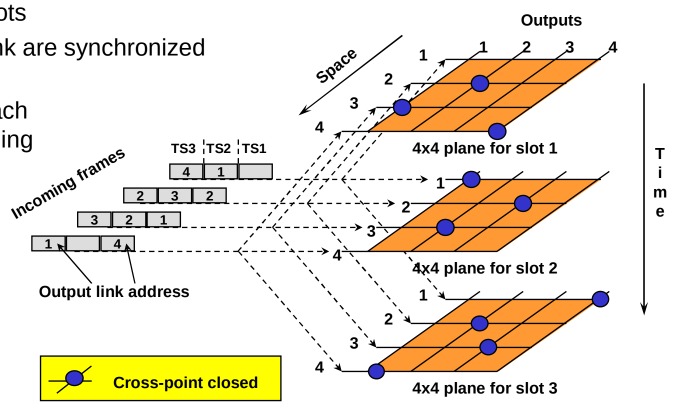
# A switch fabric as a combination of space and time switches (cont.)

- ST-switch gives high blocking probability (S-switch can develop blocking on an arbitrary bus, e.g. slots from two different buses attempting to flow to a common output)
- TS-switch has low blocking probability, because T-switch allows rearrangement of time-slots so that S-switching can be done blocking free



# Time multiplexed space (TMS) switch

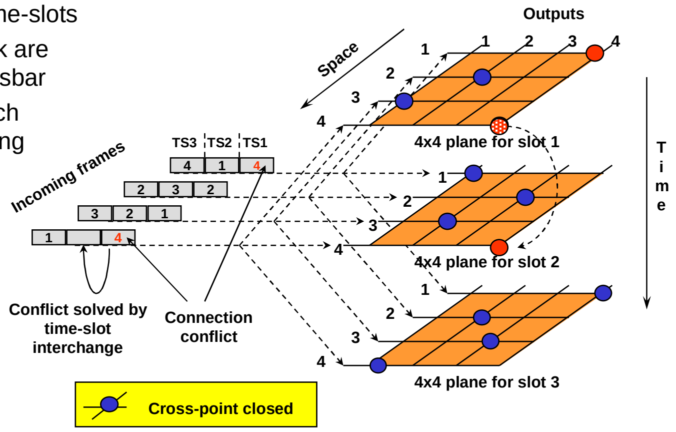
- Space divided inputs and each of them carry a frame of three time-slots
- Input frames on each link are synchronized to the crossbar
- A switching plane for each time-slot to direct incoming slots to destined output links of the corresponding time-slot





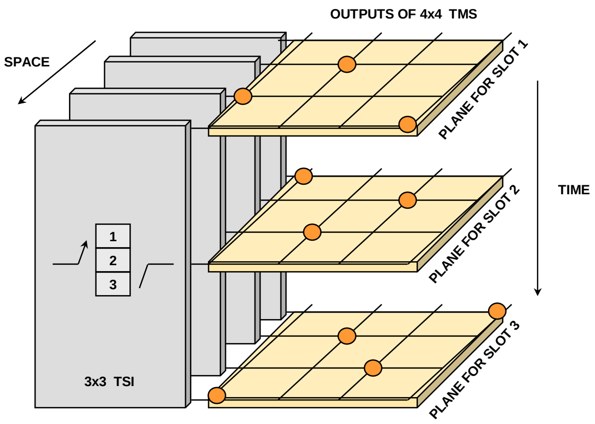

# Connection conflicts in a TMS switch

- Space divided inputs and each of them carry a frame of three time-slots
- Input frames on each link are synchronized to the crossbar
- A switching plane for each time-slot to direct incoming slots to destined output links of the corresponding time-slot



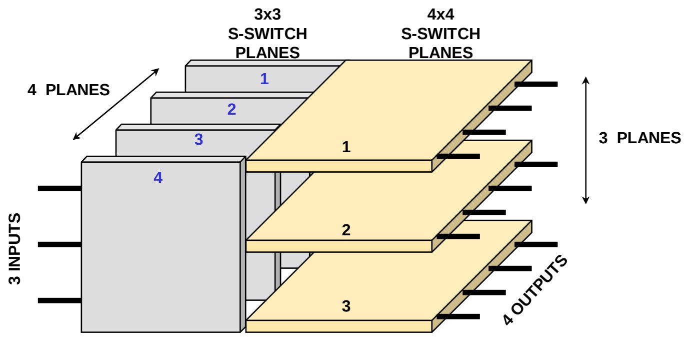
# TS switch interconnecting TDM links

- Time division switching applied prior to space switching
- Incoming time-slots can always be rearranged such that output requests become conflict free for each slot of a frame, provided that the number of requests for each output is no more than the number of slots in a frame






# SS equivalent of a TS-switch

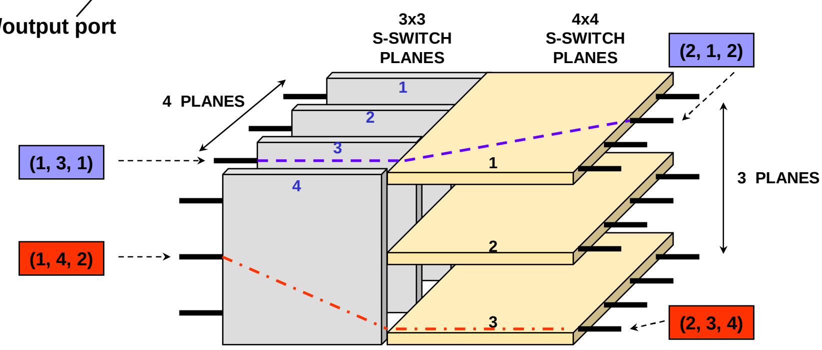


# Connections through SS-switch

Coordinate (X, Y, Z)

**stage**
**plane**
**input/output port**

**Example connections:**
- **(1, 3, 1) => (2, 1, 2)**
- **(1, 4, 2) => (2, 3, 4)**






# Switch fabrics

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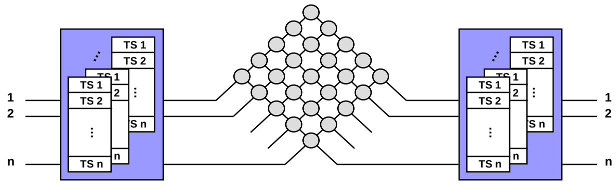
# Three stage switches

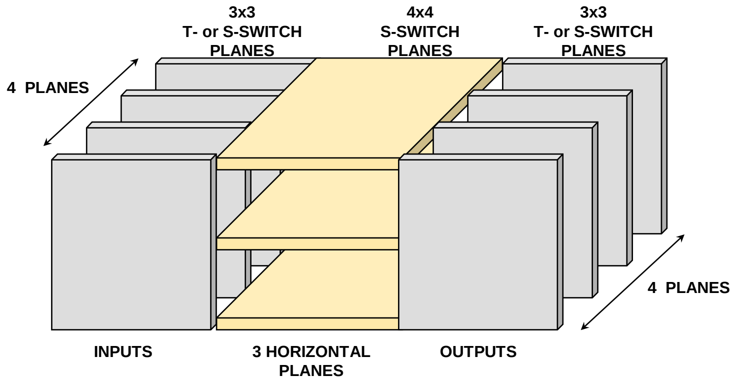
- Basic TS-switch sufficient for switching time-slots onto addressed outputs, but slots can appear in any order in the output frame
- If a specific input slot is to carry data of a specific output slot then a time-slot interchanger is needed at each output
  => any time-slot on any input can be connected to any time-slot on any output
  => blocking probability minimized
- Such a 3-stage configuration is named TST-switching (equivalent to 3-stage SSS-switching)

TST-switch:






# SSS presentation of TST-switch



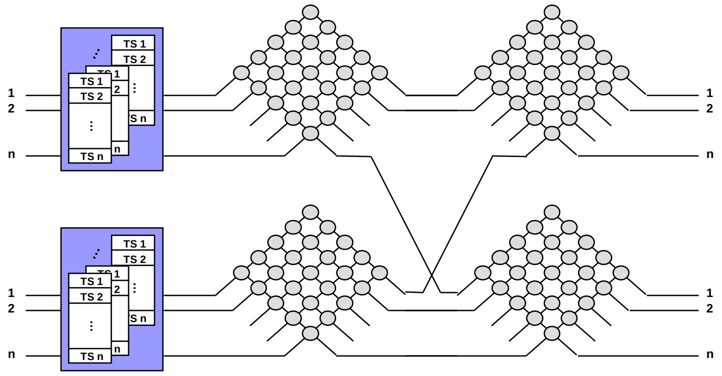
# Three stage switch combinations

- Possible three stage switch combinations:
  - Time-Time-Time (TTT) ( not significant, no connection from PCM to PCM)
  - Time-Time-Space (TTS) (=TS)
  - Time-Space-Time (TST)
  - Time-Space-Space (TSS)
  - Space-Time-Time (STT) (=ST)
  - Space-Time-Space (STS)
  - Space-Space-Time (SST) (=ST)
  - Space-Space-Space (SSS) (not significant, high probability of blocking)
- Three interesting combinations TST, TSS and STS



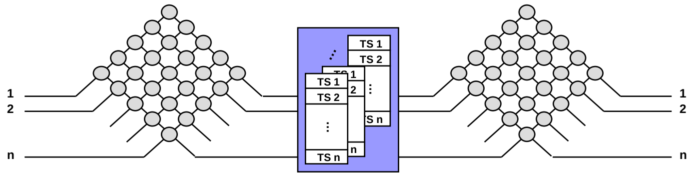
# Time-Space-Space switch

- Time-Space-Space switch can be applied to increase switching capacity



# Space-Time-Space switch

- Space-Time-Space switch has a high blocking probability (like ST-switch) - not a desired feature in public networks






# Graph presentation of space switch

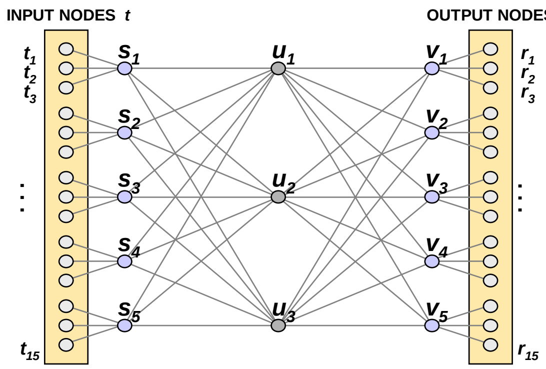
- A space division switch can be presented by a graph ***G*** = (***V***, ***E***)
  - ***V*** is the set of switching nodes
  - ***E*** is the set of edges in the graph
- An edge ***e*** ∈ ***E*** is an ordered pair (***u***,***v***) ∈ ***V***
  - more than one edge can exist between ***u*** and ***v***
  - edges can be considered to be bi-directional
- ***V*** includes two special sets *(**T** and **R**)* of nodes not considered part of switching network
  - ***T*** is a set of transmitting nodes having only outgoing edges (input nodes to switch)
  - ***R*** is a set of receiving node having only incoming edges (output nodes from switch)

# Graph presentation of space switch (cont.)

- A connection requirement is specified for each $\boldsymbol{t} \in \boldsymbol{T}$ by subset $\boldsymbol{R_t} \in \boldsymbol{R}$ to which $\boldsymbol{t}$ must be connected
  - subsets $\boldsymbol{R_t}$ are disjoint for different $\boldsymbol{t}$
  - in case of multi-cast $\boldsymbol{R_t}$ contains more than one element for each $t$
- A path is a sequence of edges $(t,a), (a,b), (b,c), \ldots ,(f,g), (g,r) \in \boldsymbol{E}$, $\boldsymbol{t} \in \boldsymbol{T}$, $\boldsymbol{r} \in \boldsymbol{R}$ and $a,b,c,\ldots,f,g$ are distinct elements of $V - (T+R)$
- Paths originating from different $t$ may not use the same edge
- Paths originating from the same $t$ may use the same edges



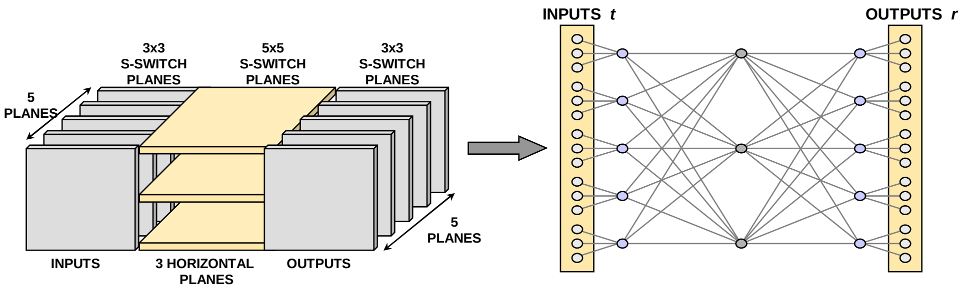
# Graph presentation example




$\boldsymbol{V = (t_1, t_2 ,\ldots t_{15}, s_1, s_2 ,\ldots s_5 , u_1, u_2 , u_3 , v_1, v_2 ,\ldots v_5 , r_1, r_2 ,\ldots r_{15})}$

$\boldsymbol{E = \{(t_1, s_1), \ldots(t_{15} , s_5), (s_1, u_1), (s_1, u_2) ,\ldots (s_5, u_3), (u_1, v_1 ), (u_1, v_2 ), \ldots (u_3, v_5 ), (v_1, r_1 ), (v_1, r_2 ),\ldots (v_5, r_{15})\}}$

# SSS-switch and its graph presentation



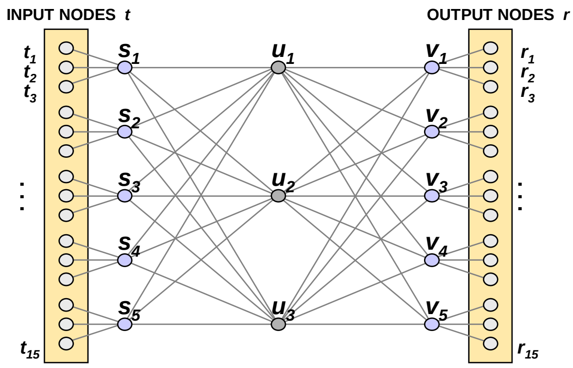



# Graph presentation of connections

***Establish connections:***

***Path 1*** = {($t_{11}$, $s_4$), ($s_4$, $u_1$), ($u_1$, $v_2$) , ($v_2$, $r_5$ )}

***Path 2*** = {($t_4$, $s_2$), ($s_2$, $u_2$), ($u_2$, $v_1$ ) , ($v_1$, $r_2$ ), ($u_2$, $v_4$ ), ($v_4$, $r_{11}$)}



# Graph presentation of connections (cont.)