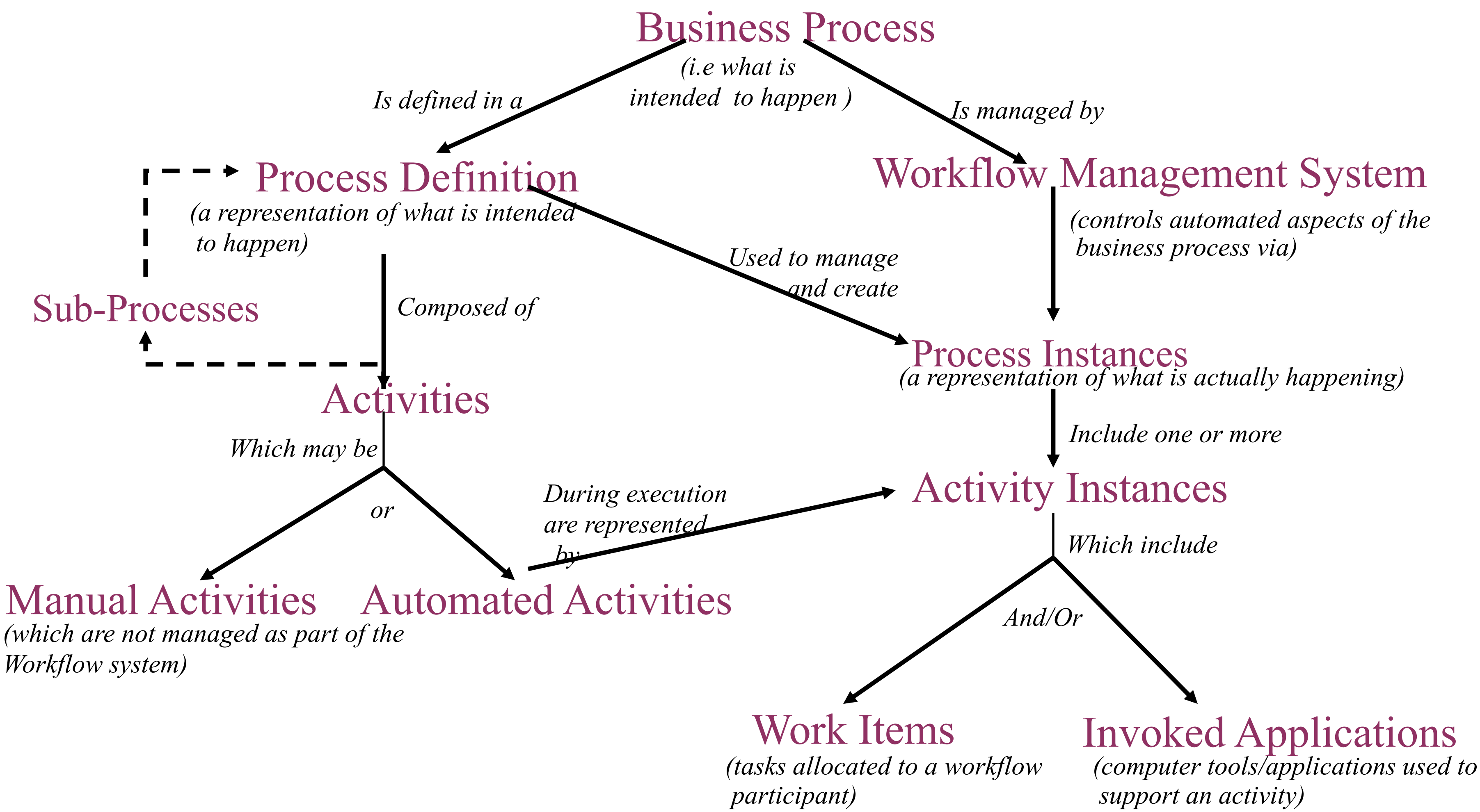
Workflow Management Systems

WORKFLOW MANAGEMENT SYSTEMS

- Workflow management is the automated coordination, control and communication of work, both of people and computers, in the context of organizational processes, through the execution of software in a network of computers whose order of execution is controlled by a computerized representation of the business processes
- Workflow management system: "a system that defines, creates and manages the execution of workflows through the use of software, running on one or more workflow engines, which is able to interpret the process definition, interact with workflow participants and, where required, invoke IT tools and applications" [WFM Coalition]

ANATOMY OF WORKFLOW MANAGEMENT



WFMS FEATURES

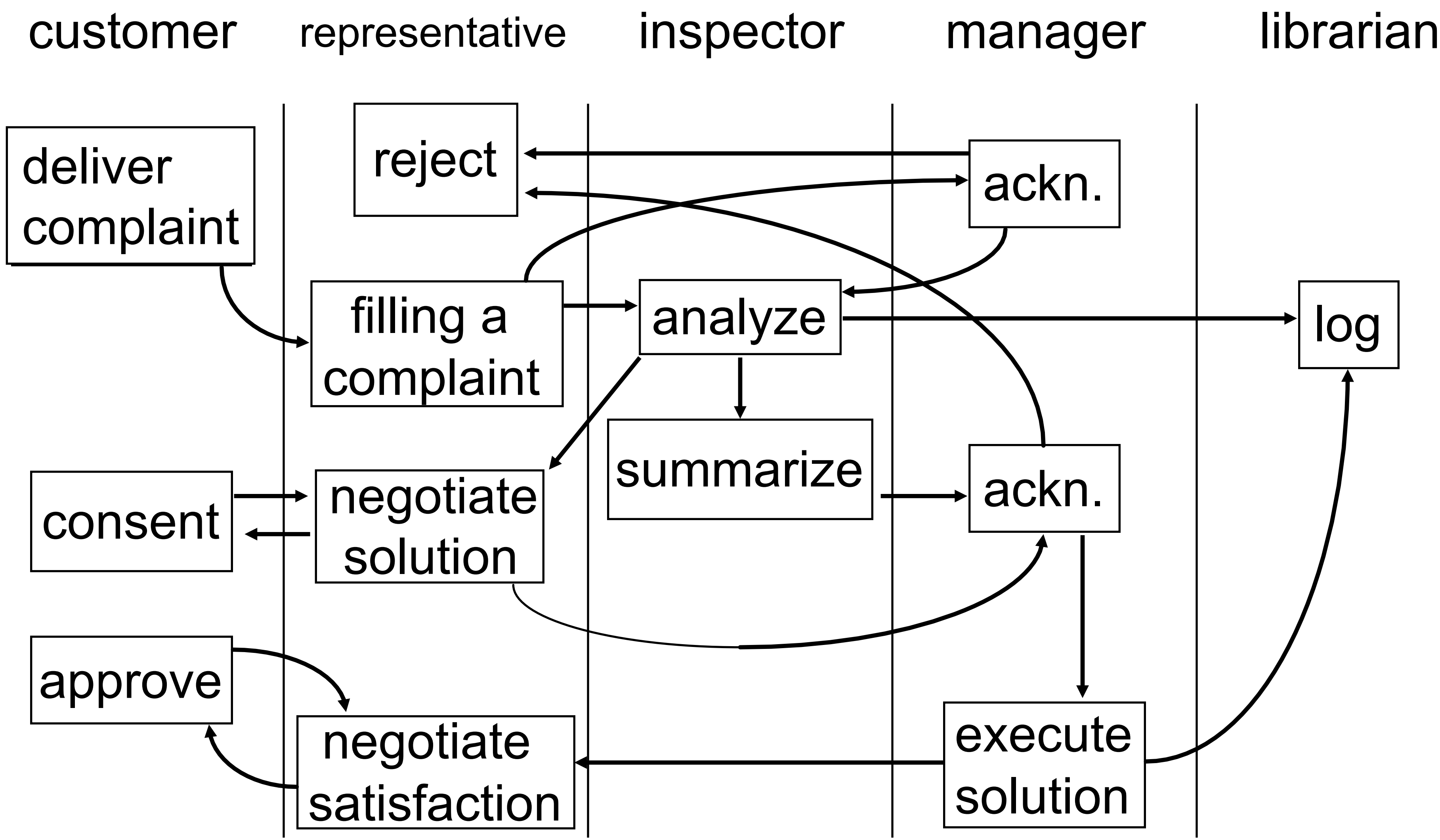
- Monitoring, tracking, auditing, reporting
- Authorization; Security
- Interoperability
- Multiple computing platforms and communications infrastructures
- Load balancing
- Versioning and life-cycle
- Scalability: Partly distributed enactment service (multiple server support); Fully distributed enactment service
- Cloud support

WFMS FEATURES

PROCESS ANALYSIS

- Purpose: To ensure that the right people understand the necessary facts about an organizational process.
- Objectives:
  - shared understanding
  - trigger model (event-driven)
- How to:
  - Who to talk to? (roles)
  - What do you do? (activities)
  - What prompts you to do it? (triggers)
  - Follow links, and repeat.
- Using: interviews (time consuming, rich secondary information), meetings (quick, obscure social process)

EXAMPLE: COMPLAINT PROCEDURE



BASIC MODEL COMPONENTS

- Workflow (process) class (schema) to model a(n) (business / organizational) process
- Task, activity or step
- Task coordination / linking or Control flow (serial / parallel-resync/list/queues/network, rules/triggers, dependencies / conditions)
- Data flow or sharing (explicit passing, shared data, common variables)
- Processing entities: Users-roles and authorization, worklists; Information Systems

WORKFLOW MODELLING

- Workflows deal with (parts of) business processes, also called cases or scenarios
  - e.g., an insurance claim, a loan application
- Similar cases belong to the same case type
- Each case has a unique identity
- Cases have a limited lifetime: from the point in time the case was submitted, to the point its processing has been completed
- At any point during its lifetime, a case has a state comprising:
  - the values of the relevant attributes
  - the conditions that have been fulfilled
  - the content of the case

WORKFLOW MODELLING

- Workflows are structured in tasks
  - a task is a logical unit of work
  - regarded as indivisible or atomic (either executed in full or if its execution is stopped, a rollback to the previous state takes place)
- Tasks are distinguished into
  - manual: performed by humans without IT support
  - automatic: performed without human intervention
  - semi-automatic: involve both humans and application programs

APPLICATION/AUTOMATIC TASKS

- Application tasks involve
  - scripts for terminal emulation to remote systems
  - Web services
  - application programs/systems providing data manipulation (filters)
  - predefined interfaces to legacy application systems
  - stored procedure calls
  - client programs or servers invoking other servers
  - database transactions

WORKFLOW MODELLING

- Tasks refer to generic pieces of work and not to performing a particular activity for a specific case
- Task ≈ work item
- Activity ≈ task execution for particular case
- A process specifies the way in which a particular category of cases should be carried out and in what order.]A process can be viewed as a procedure for a particular case type.
- Different cases can be handled using a single process
- A process is made up of tasks and conditions and may include sub-processes
- Complex processes can be structured hierarchically
- Each process has a beginning and an end which mark the initiation and completion of a case.

WORKFLOW MODELLING

- Workflow scheduling or routing: basic constructs
  - sequential task execution: implies a dependency between tasks that follow one another; the result of one task is input to the next
  - parallel task execution: tasks that need to be executed simultaneously without the result of one affecting the other. Parallel tasks are initiated using an AND-split and later resynchronized using an AND-join
  - selective routing: choice between two or more tasks (depending upon specific properties of the case). Choice also known as an OR-split. Alternative paths are reunited using an OR-join.
  - iteration: performing a particular task a number of times

TYPES OF PROCESSING ENTITIES

- humans (may appear as a GUI; may use document/image processing systems and applications)
- script interpreters and compilers (for processing scripts and application programs)
- (legacy) application systems
- servers in client-server and transaction processing systems
- DBMSs

ADDITIONAL MODELLING FEATURES

- Tasks: non-transactional, transactional
- Execution environment / infrastructure / configuration: execution location, interfaces
- Deadlines
- Exception Handling (Error Handling, Recovery) specification

WORKFLOW MODELLING & ANALYSIS

- Workflow enactment
  - the enactment of work items is triggered by resources (human or automated), an external event or a time signal
- Workflow modelling and analysis must be carried out formally
  - forces precise definitions avoiding ambiguities, uncertainties and contradictions (contrary to many semi-formal diagrammatic techniques)
  - formalisms can be used to reason about processes (e.g., whether a case is successfully completed after a period of time, whether "liveness" or "safety" properties are maintained etc.)

WORKFLOW (SPECIFICATION) ANALYSIS

"A clear theoretical basis and correctness criteria must be established which enable the runtime system to efficiently reason about the correctness of a requested change ..."

- Types of Analysis
  - Validation - interactive simulation (Are we building the right product?)
  - Verification (establishing correctness of a workflow) - advanced analysis techniques (Are we building the product right?)
  - Performance Analysis - throughput etc.

CORRECTNESS CRITERIA

- Structural properties
  - Control flow, Data flow, Temporal constraints
  - Reachability, Termination, Deadlocks, Data inconsistency, Missing input data
- Other Workflow characteristics
  - Reassignment of task to agents
  - Changes in organizational schema
  - Access to external databases

FORMAL BASIS FOR MODELS

- High level Petri nets
- State and Activity charts
- Temporal logic
- Process Algebra
- Graph based models
- Rules

But there are limitations wrt to what is modeled using formal models. Often limited to workflow maps/graphs, inter-task dependencies.

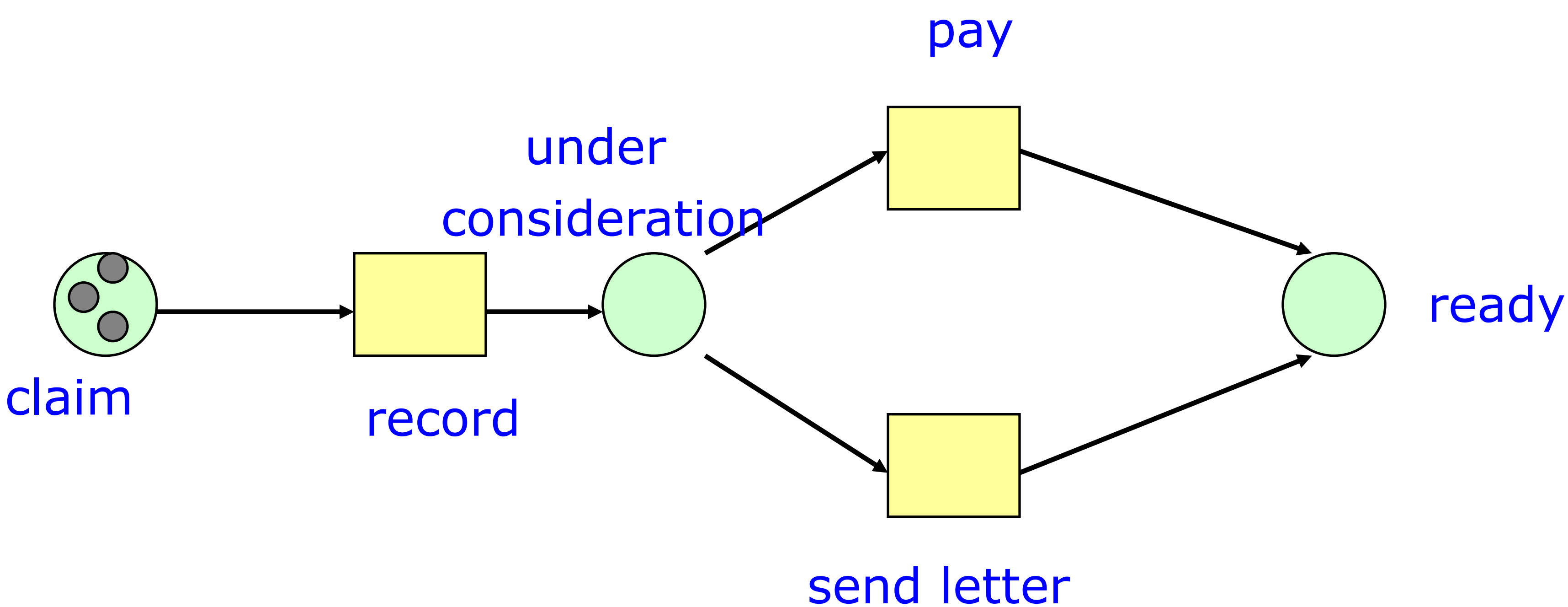
PETRI NETS

- a formalism for modeling and analyzing workflows
  - devised by Carl Petri (1962) as a tool for process modeling and analysis
- processes can be described graphically and in addition they possess a mathematical foundation
- A Petri Net (PN) consists of places and transitions denoted by circles and rectangles respectively
  - E.g., the *claim processing* PN may have the places *claim*, *under consideration* and *ready* and the transitions *record*, *pay* and *send letter*
- Places symbolize states, conditions, or resources that need to be met/be available before an action can be carried out. Transitions symbolize actions
- places and transitions are connected by directed edges (place → transition, transition → place, but not between places or transitions)

PETRI NETS

- A place p is called an input place for a transition t if there is an edge from p to t
- A place p is called an output place for a transition t if there is an edge from t to p
- Places may contain tokens (denoted by black dots)
- Although the structure of a PN is fixed, the distribution of tokens among the places may change
- The state of a PN is indicated by the distribution of tokens in the places of the net
- Firing a transition results in tokens moving from input places to output places.

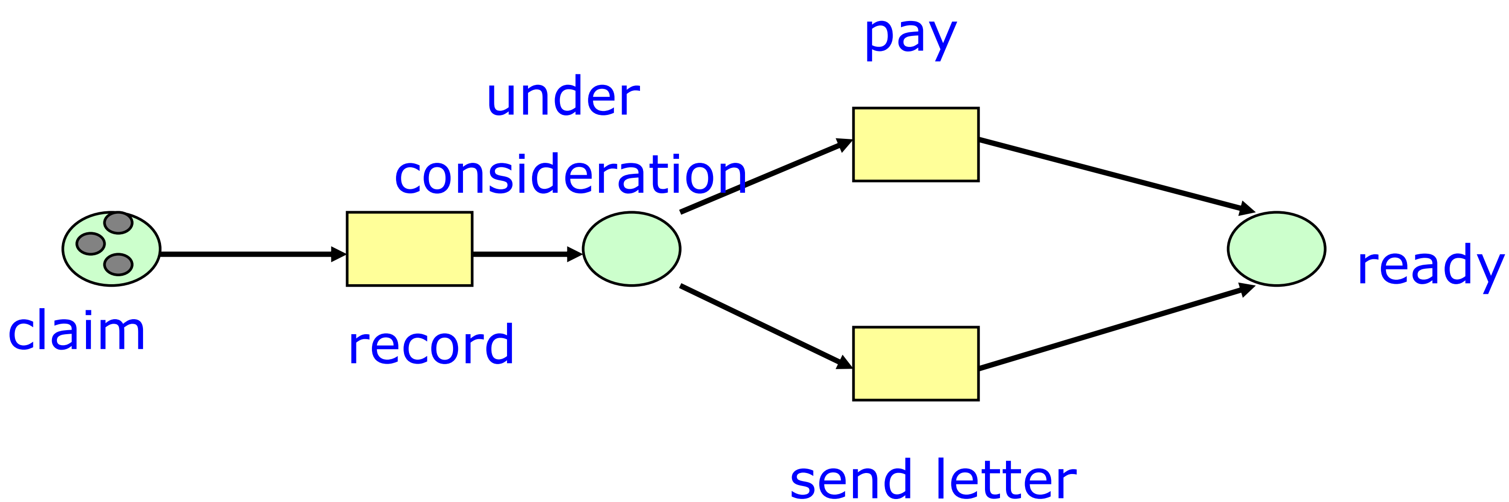
PETRI NETS



The state may be represented as the vector (3,0,0)

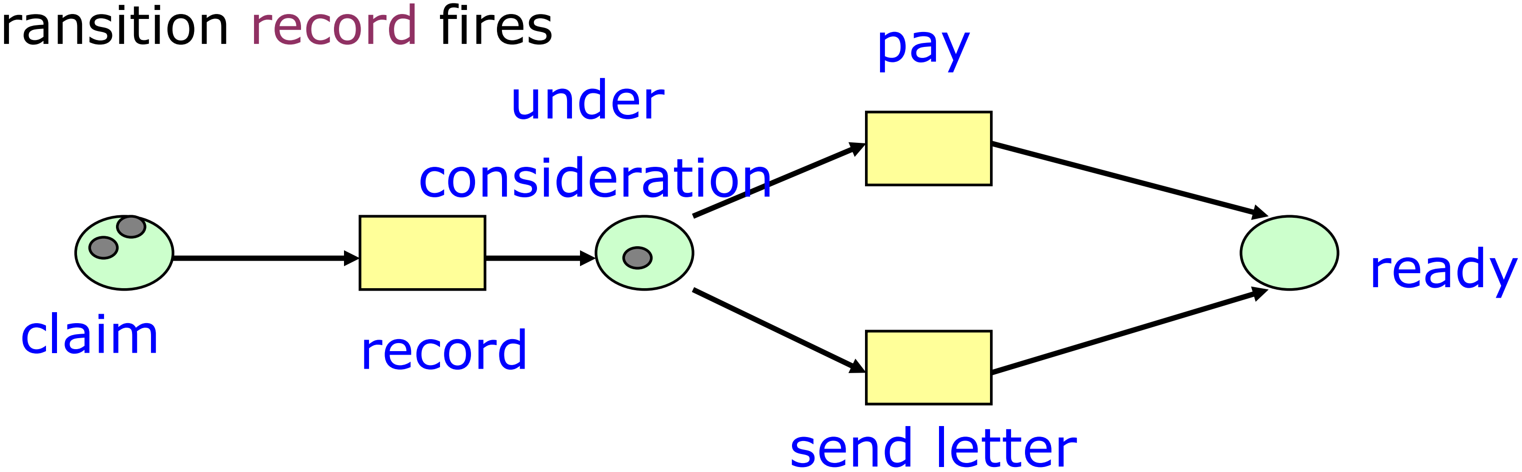
PETRI NETS

- A transition may fire if it is enabled, i.e., there exists at least one token in each of its input places
- When a transition fires, one token is removed from each input place and one token is added to the output place
- Tokens are consumed from input places and produced at output places

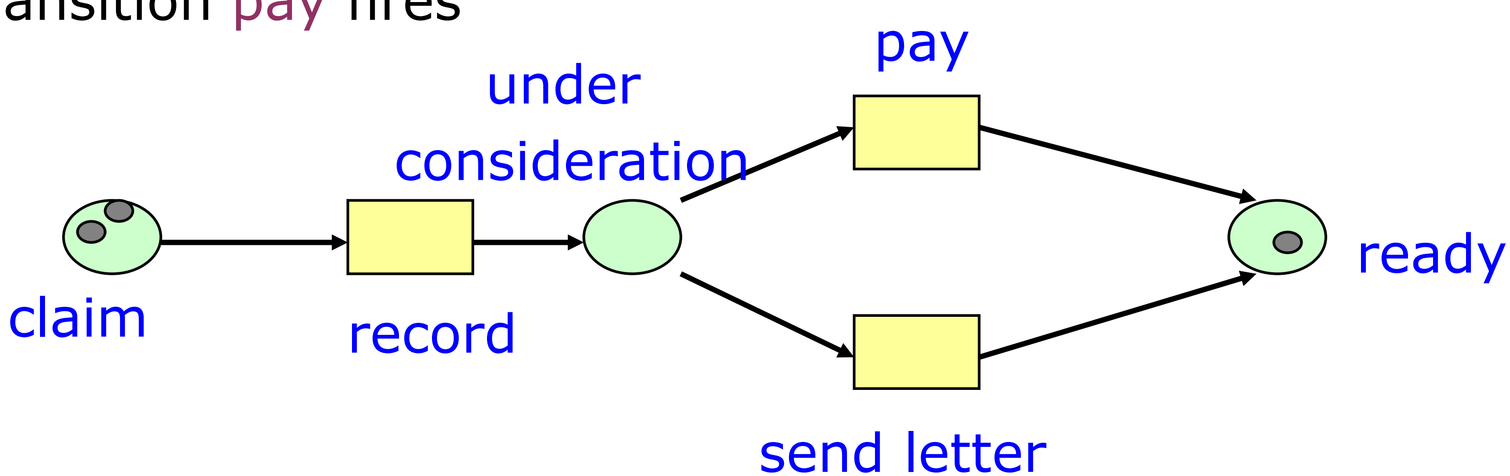


PETRI NETS

After transition record fires



After transition pay fires

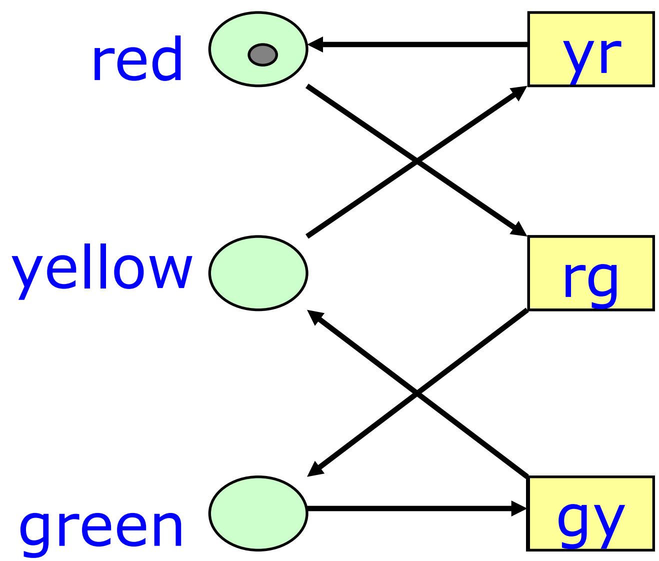


PETRI NETS

- When a transition fires, the process shifts from one state to another
- Transitions represent event occurrences, operations, transformations etc. and are the active components of a P.N.
- Places are passive: they cannot change the state of the net; they represent particular conditions
- Tokens represent objects (physical, informational etc.)
- More than one case can be in progress simultaneously in a PN
- A PN can also be used to describe repetitive processes

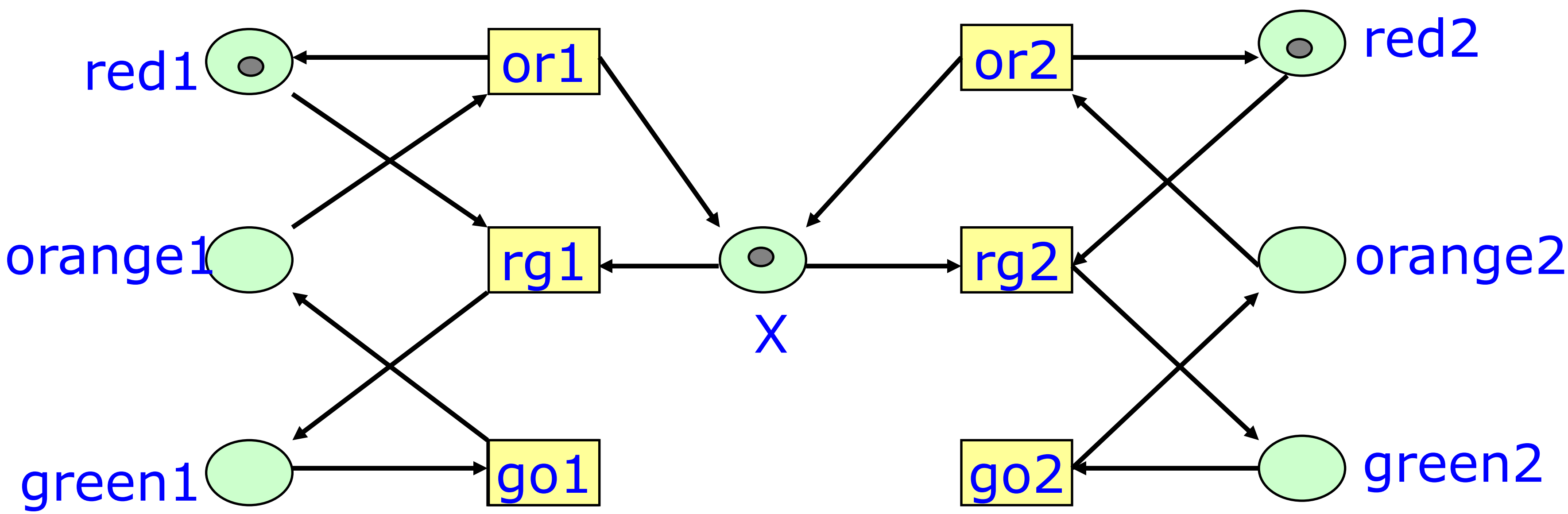
PETRI NETS

- Example: a traffic light process for crossing a street



PETRI NETS

- Example: two traffic light processes for crossing two 1-way streets
  - Requirement: one of the two must always be red



PETRI NETS

- Apart from the graphical notation provided by PNs, one must be able to determine that the process modeled will operate safely.
  - we will study analysis techniques later in the course
- PNs may become too large and difficult to use. Several extensions have been proposed:
  - Colored Petri Nets
  - Temporal Petri Nets
  - Hierarchical Petri Nets

… collectively referred to as high-level Petri Nets

THE WEAKNESSES OF TRADITIONAL PETRI NETS

- Their primary aim is to represent the dynamic aspects of system behavior and because of this they do not have anything other than very simple capacity to represent entities of the domain of application.
- Data representation is limited to tokens which are indistinguishable from each other.
- Clearly this is inadequate for representing IT systems.

Source: http://www.dit.ie/computing/

COLORED PETRI NETS

- Colored Petri Nets combine the strength of Petri nets with the strength of programming languages.
- Petri nets provide the primitives for the description of the synchronisation of concurrent processes, while programming languages provide the primitives for the definition of data types and the manipulation of data values.

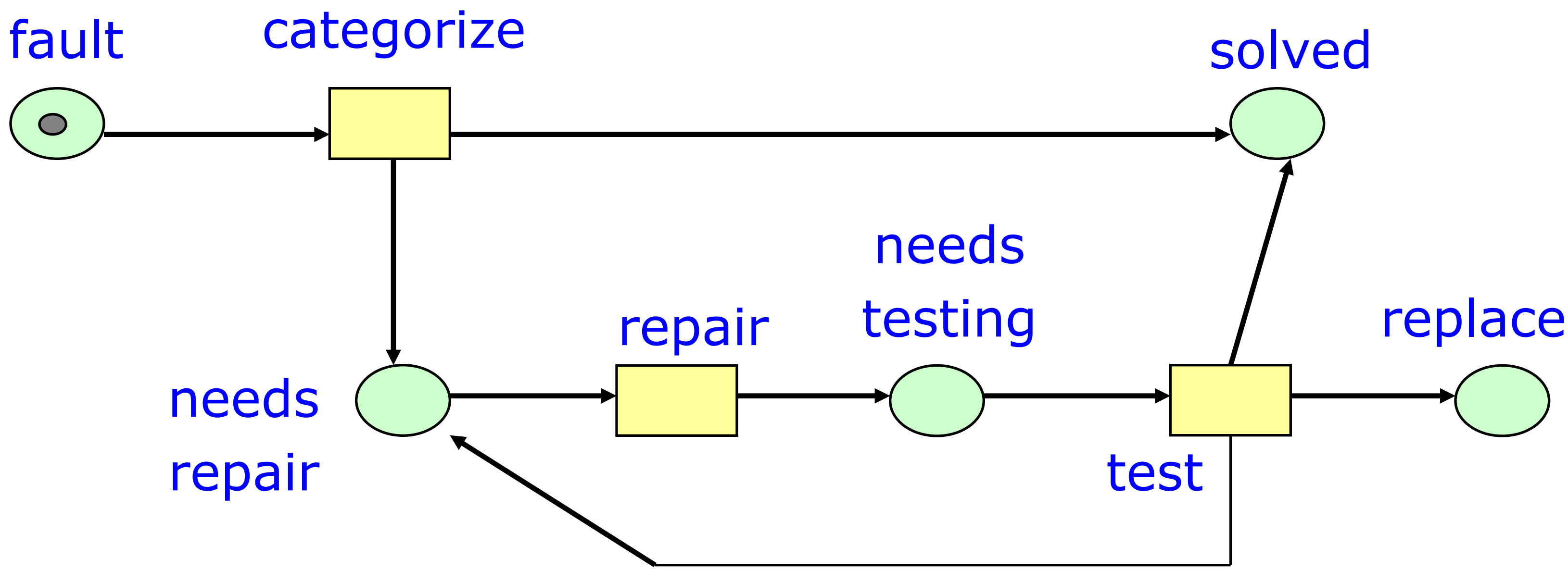
COLORED PETRI NETS

- In classic PN tokens found in the same place are by definition indistinguishable.
- There is a need to represent different aspects or attributes of objects.
- In colored PN each token has a value or color.
- Transitions that fire produce tokens whose values depend on the values of the tokens consumed.
- The number of tokens produced by a transition also depends on the values of the tokens consumed.
- This provides a greater flexibility in representing different cases of processes.
- Like traditional Petri Nets Colored Petri Nets consist of Places,Transitions, connected by Arcs (forming a bi-partite graph).
- They are a combination of text and graphics.

COLORED PETRI NETS

- Example: Dealing with technical faults in a product department
  - faults are categorized
  - if they cannot be corrected right away, a repair takes place and it is tested yielding three possible results:
    1. Fault has been corrected
    2. Further repair is required
    3. Faulty component must be replaced
- A token value represents relevant properties of the fault that needs to be dealt with and this value is retained throughout the tokens' trajectory in the net

COLORED PETRI NETS



- An output place may not receive a token: depending on the transition categorize, a fault will be either solved or a repair will be needed.
- Transition test may produce a token in one of 3 possible places

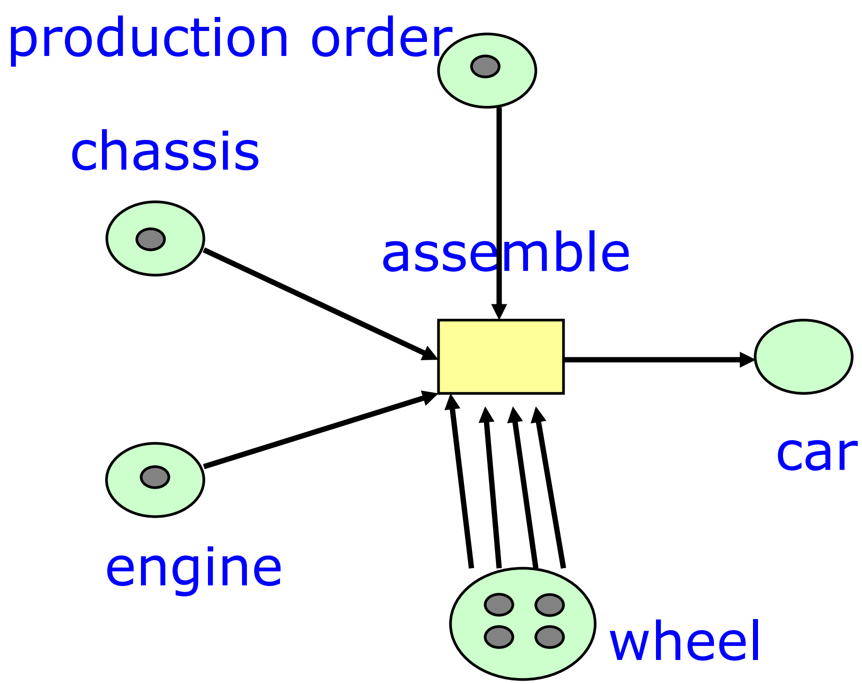
COLORED PETRI NETS

- In colored PN, conditions can be set for the values of tokens to be consumed
- A transition is only enabled if there is a token at each of its input places and the preconditions for firing the transition are met
- Preconditions are logical expressions referring to the values of tokens
  - E.g., the transition categorize may have the precondition "the value of the token to be consumed from the place fault must contain a valid component id"
  - in this case, a fault missing a valid id will not be categorized (transition not fired; remain in the place fault)

COLORED PETRI NETS

- Preconditions can also be used to synchronize tokens, i.e., to specify that a transition will fire only if a particular combination of tokens can be consumed

- Example: car assembly process



- when a transition fires the number of input tokens must be equal to the number of incoming arrows
- a precondition must specify that tokens can only be consumed in a certain combination (and not at random)

COLORED PETRI NETS

- The examples show that not all the required information can be represented graphically.
- For each transition, we need to specify:
  - the precondition for firing the transition (if one exists)
  - the number of tokens produced in each output place when the transition fires
  - the values of the tokens produced
- This information can be specified as text (pseudo-code) or as a subroutine in a programming language or as a formal specification

PLACES

- *Places are specified with* the following inscriptions:
  - *Name* (for identification).
  - *Color set* (specifying the type of tokens which may reside on the place).
  - *Initial marking* (multi-set of token colors)

TRANSITIONS

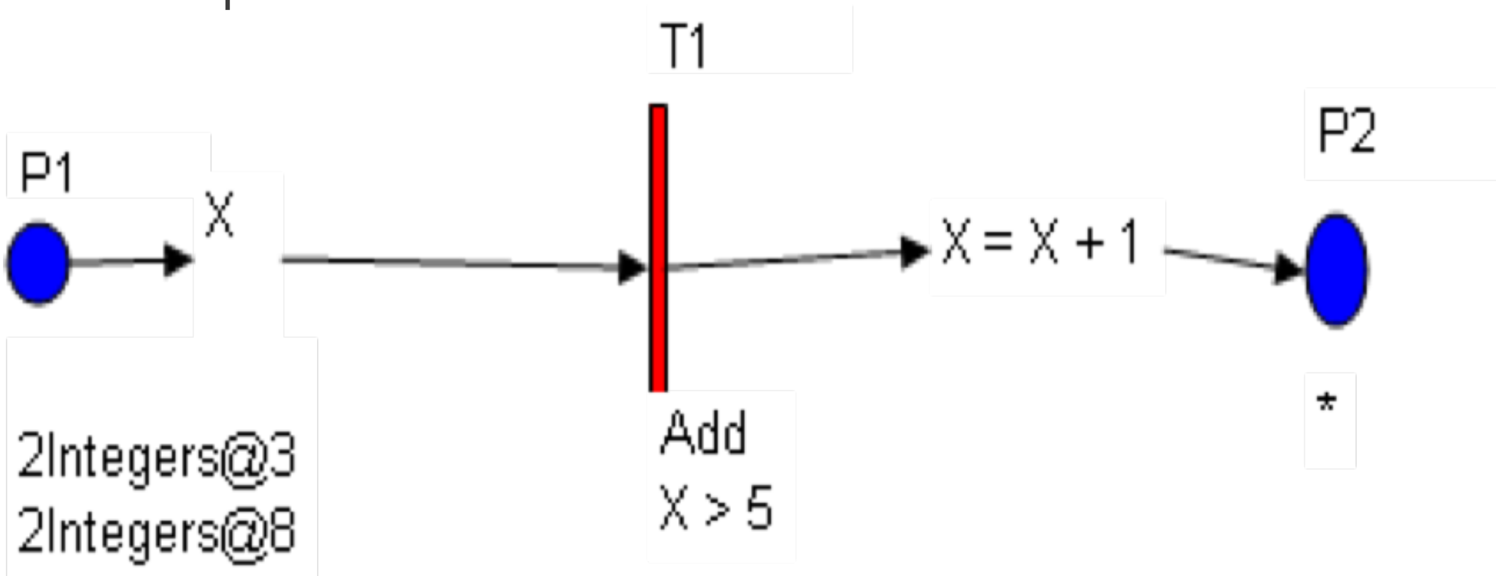
- Each *transition* has the following inscriptions:
  - *Name* (for identification).
  - *Guard* (boolean expression containing some of the variables).

ARCS

- Each *arc* has the following inscriptions:
  - *Arc expression* (containing some of the variables).
- When the arc expression is evaluated it yields a multi-set of token colors.

EXAMPLE

- Place P2 is empty.
- The marking at P1 consists of 2 tokens of type integer whose value is 3 and
- 2 tokens of type integer whose value is 8.
- On T1 is the guard X > 5. This is a barrier to T1 happening, in that T1 will only pass if the assignment to X under the occurrence in question is greater than 5.
- As we will see these guards on transitions will play an important part in representing the barriers to the performance of activities .



THE ARC EXPRESSION

- On the arc between P1 and T1 is the atomic expression consisting of a variable X to which may be bound one of the input tokens in P1. Such a binding is called an occurrence.
- The expression on the output arc from T1 to P2 represents the state change which takes place across transition T1. In this example it embodies an increment of 1 on the variable X

GUARDS ON THE EXPRESSION

- The expression $X > 5$ at transition T1 is known as a guard and must be satisfied by the incoming token values.
- If the incoming tokens do not satisfy the guard then the transition cannot happen.

- In the case X has value 8 which is > 5, the transition can take place

OCCURRENCE

- The passage of tokens across transitions from place to place through this process of binding, satisfying guards and modifying data is called an occurrence.
- The occurrence will be blocked if the guard is not satisfied by the incoming tokens.
- So if an input token with value 5 was bound to X then the transition could not occur.
- The guard is a barrier to the transition happening.

TEMPORALLY-EXTENDED PETRI NETS

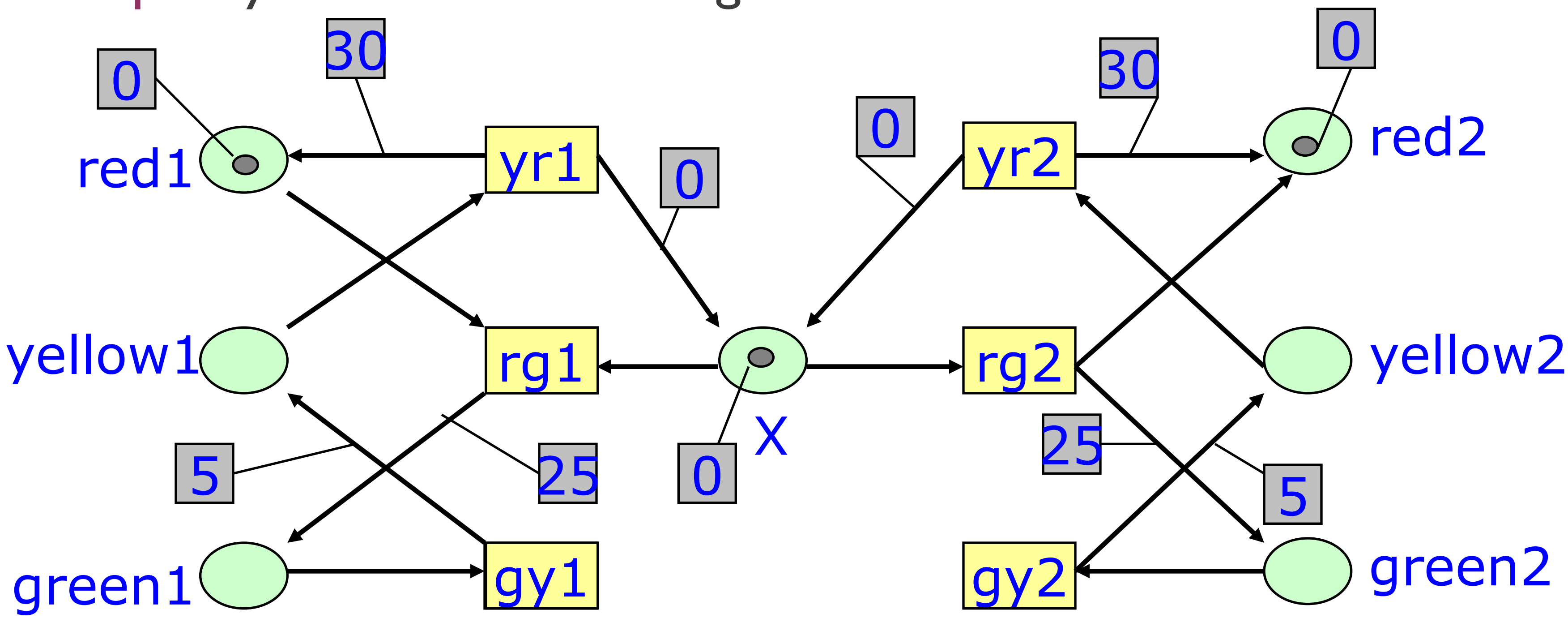
- Often, there is a need to specify expected process completion time and other information related to the timing of transitions in a PN
- Classic PN do not allow modeling time.
- In temporally-extended PN, tokens have a timestamp in addition to a value. The timestamp represents the time from which the token is available for consumption.
- Transition enabling time: earliest moment at which all its input places contain sufficient available tokens.
- Tokens are consumed in a first-in-first-out fashion.
- The transition with the earliest enabling time fires first. If more than one have the same enabling time, one is chosen randomly

TEMPORALLY-EXTENDED PETRI NETS

- Firing of a transition may affect the enabling time of other transitions
- Produced tokens have timestamp equal to or greater than the transition firing time
- There may be a delay that depends on the transition and the values of the tokens consumed
- The delay may be constant (could be 0) or may be decided randomly
- Transition firing is taken to be instantaneous

TEMPORALLY-EXTENDED PETRI NETS

- Example: synchronized traffic lights



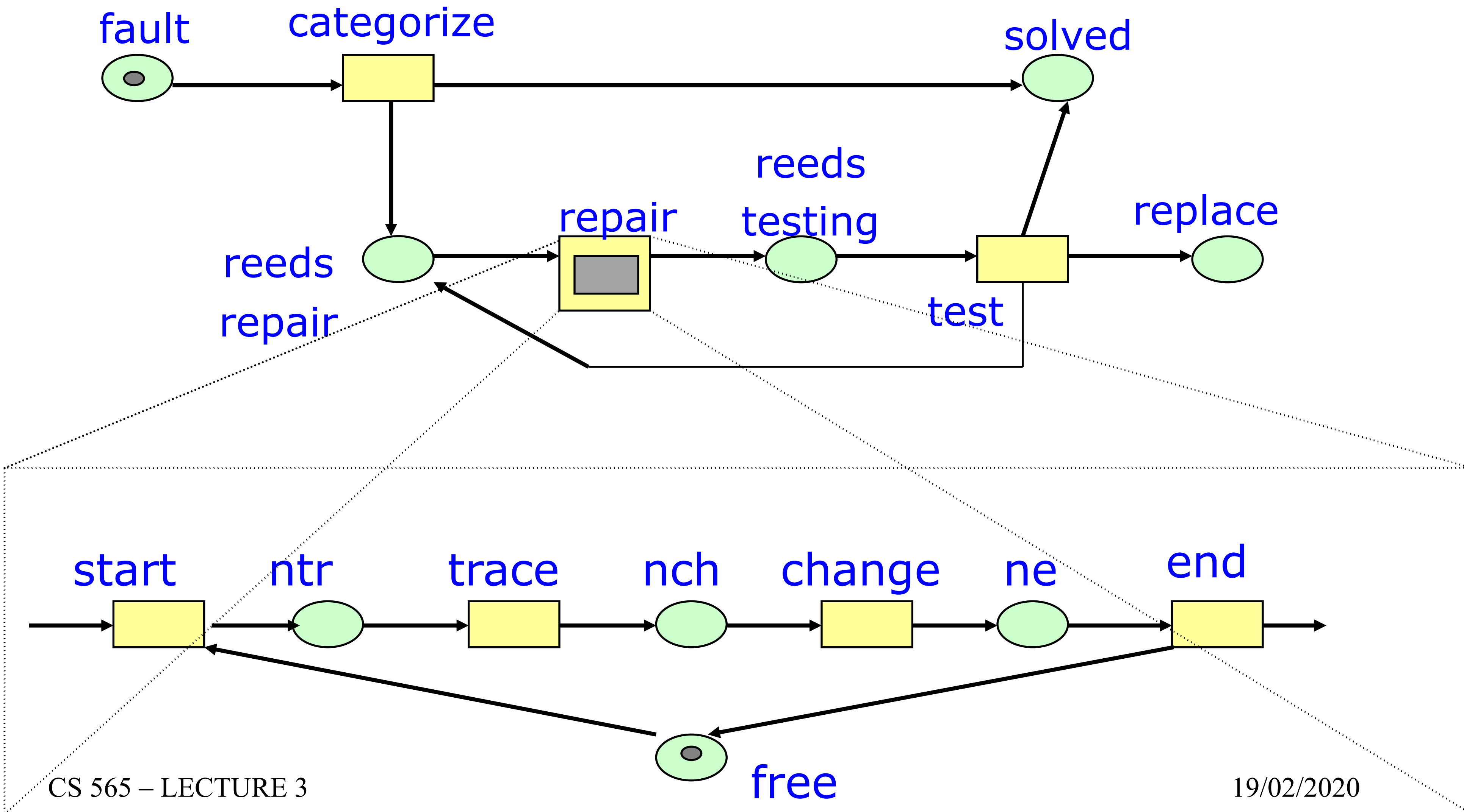
rg1 enabling time=0=rg2 enabling time

If rg1 is chosen a token will be produced at green1 with delay 25, at yellow1 with delay 30 and at red1 and X with delay 60; rg2 will fire

HIERARCHICAL PETRI NETS

- Classic, colored or temporally-extended PN have a flat structure resulting in a single, possibly extensive and complex net.
- Often processes are structured hierarchically, and can be modeled by networks containing sub-networks (sub-processes)
- This provides the ability to refine processes rather than regard them as non-decomposable.
- Graphically, non-atomic sub-processes are represented as doubly-arrowed rectangles

HIERARCHICAL PETRI NETS



HIERARCHICAL PETRI NETS

- PNs can be structured hierarchically using a bottom-up or top-down approach
  - Top-down decomposition starts with high-level processes that are gradually decomposed into sub-processes; at the lowest level, processes consist only of transitions and places
  - Bottom-up synthesis starts with elementary components that are combined into larger processes
- Complex processes are rarely non-hierarchical, hence a divide and conquer strategy is needed.
- Reuse of (sub-) processes is also possible (e.g., when a recurring process is included)

REFERENCES

- "Workflow Management: Models, methods and systems" by van der Aalst and van Hee
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- Coloured Petri Nets (http://www.cs.au.dk/~cpnbook/)
- Tutorial: http://www.informatik.uni-hamburg.de/TGI/PetriNets/introductions/pn2000_introtut.pdf)
- Animated examples: https://www.informatik.uni-hamburg.de/TGI/PetriNets/introductions/aalst/
- https://www.youtube.com/watch?v=3KJjKY8k9Lk