Distributed and Parallel Computing

Lecture 14

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The Echo Algorithm

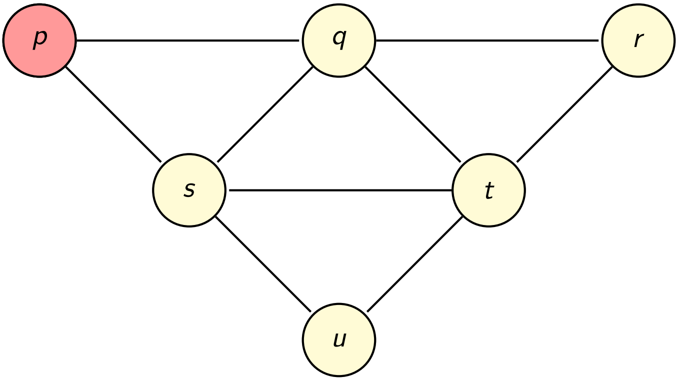
A wave, but not a traversal algorithm (so no *tokens* involved), *Echo* is a centralized algorithm (i.e. one initiator only) for undirected networks.

- Initiator sends message to all neighbours
- When a non-initiator *first* receives a message
  - It makes the sender its parent
  - It sends a message to all neighbours except its parent
- When a non-initiator has received messages from *all* its neigbours
  - It sends a message to its parent
- When the initiator has received messages from all its neighbours, it *decides* and the algorithm terminates

This algorithm builds a spanning tree

Example Execution of the Echo Algorithm

Here if messages are sent out immediately after each other without waiting to receive a message in between sends, they are given the same number. In reality, real messages are not sent simultaneously.



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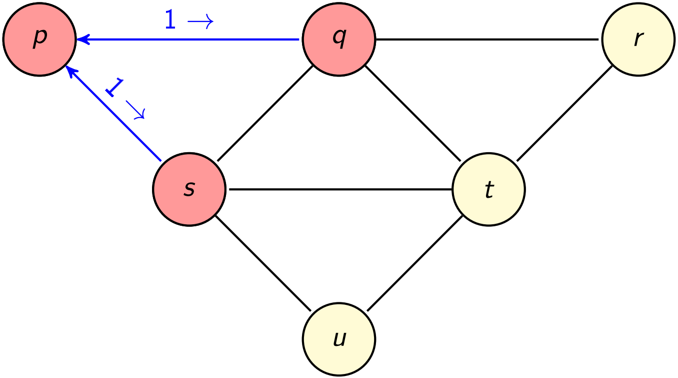

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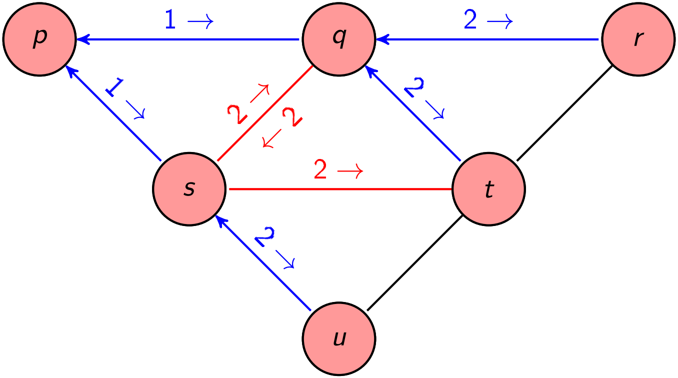

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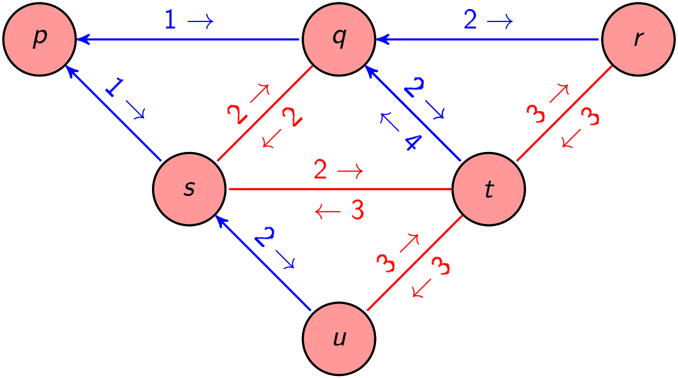

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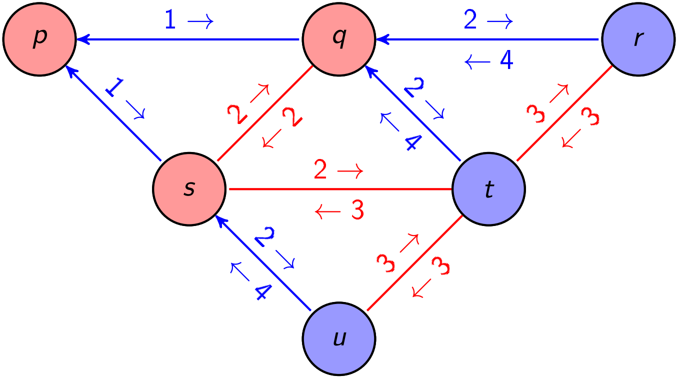

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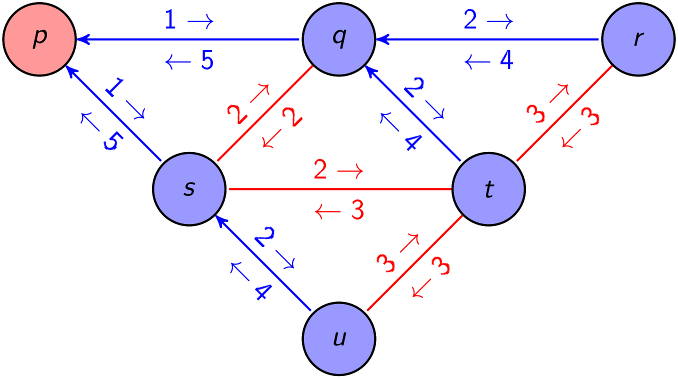

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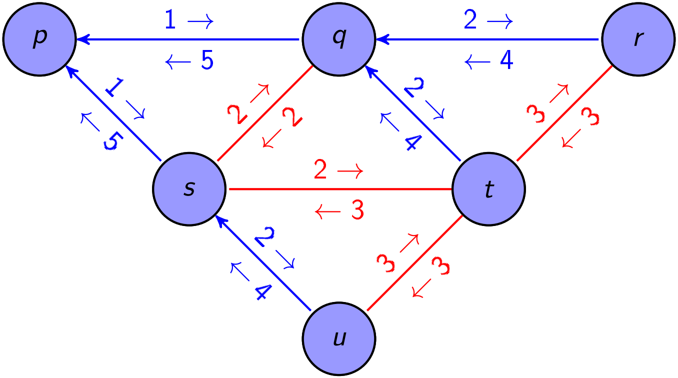

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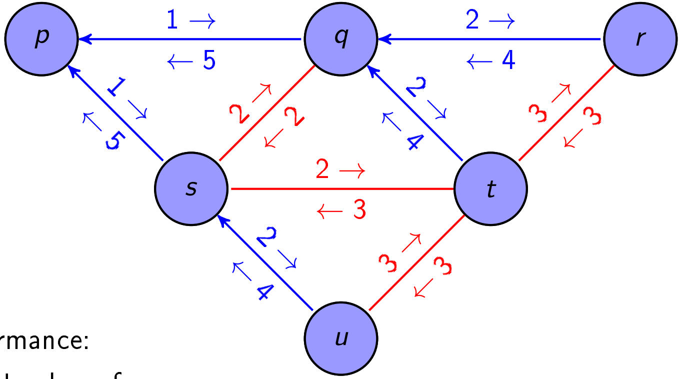

Performance:

- Number of messages:
- Worst case time to complete:

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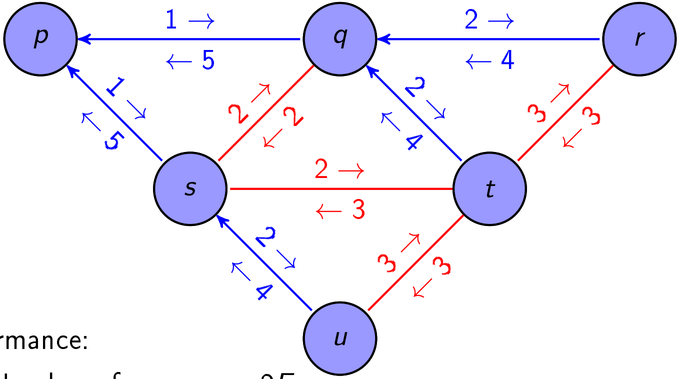

Performance:

- Number of messages: $2E$
- Worst case time to complete:

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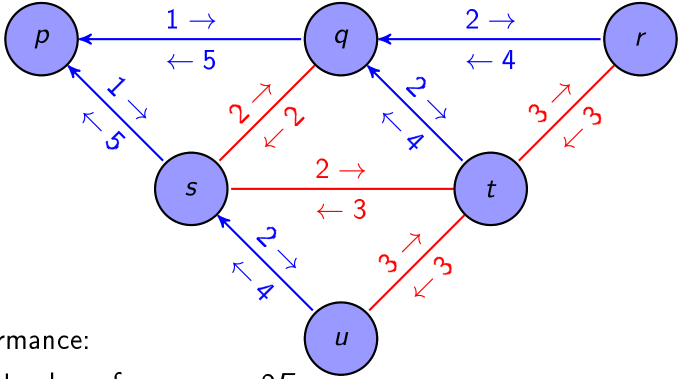
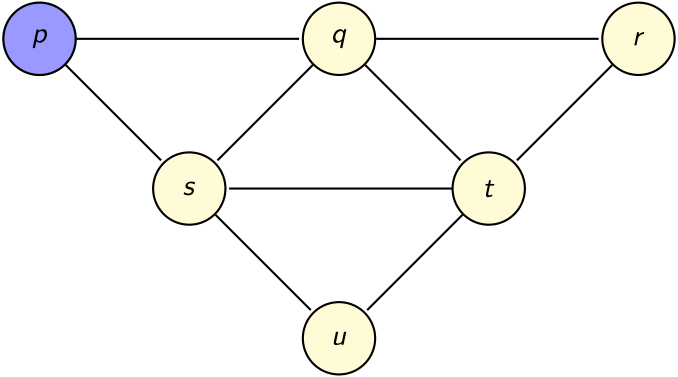


Performance:

- Number of messages: $2E$
- Worst case time to complete: $2N - 2$ time units

Tarry Algorithm considered as an Echo Algorithm



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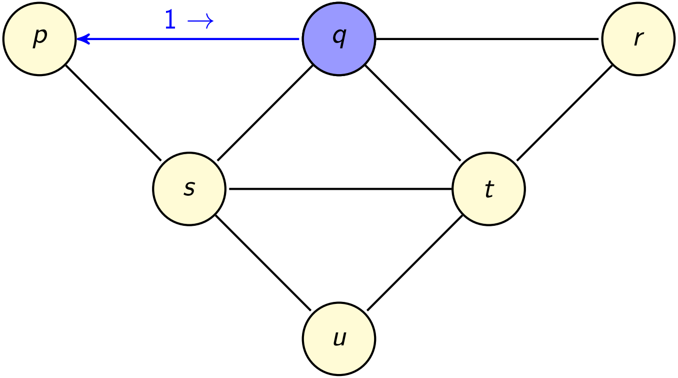

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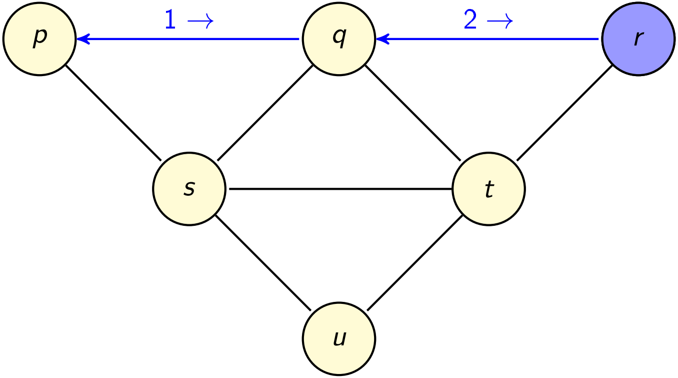

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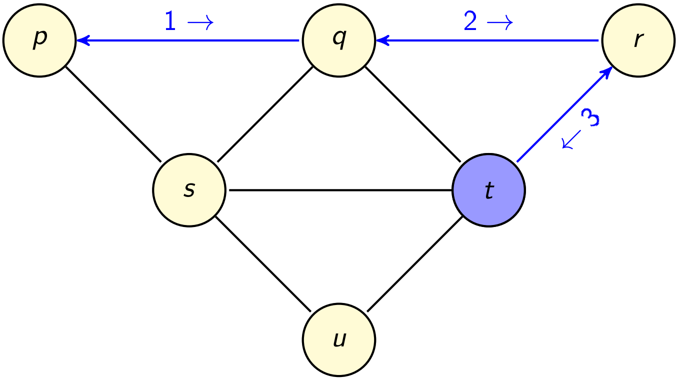

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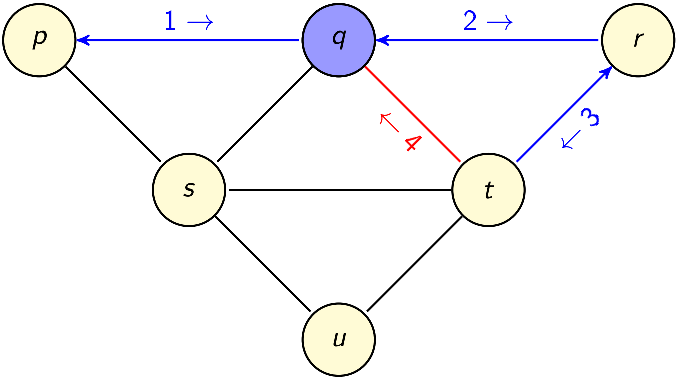

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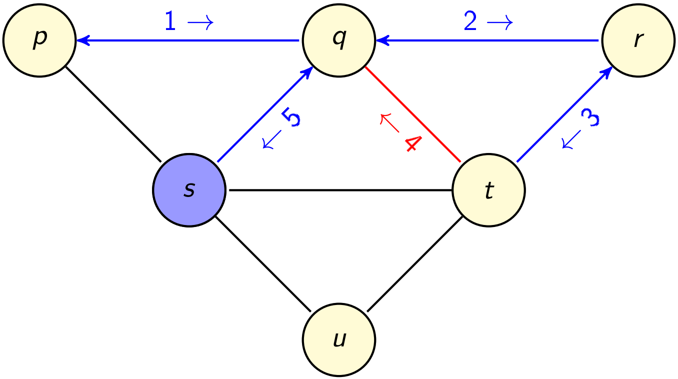

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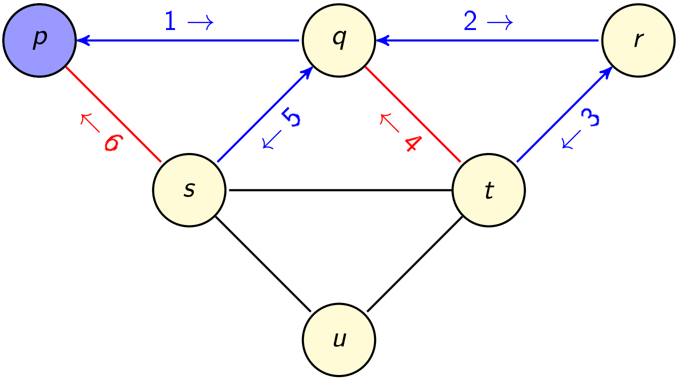

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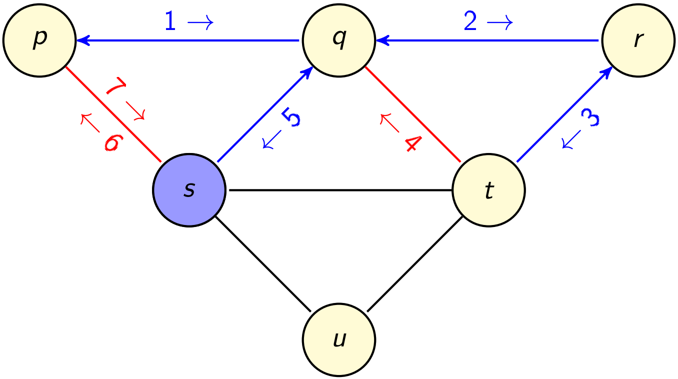

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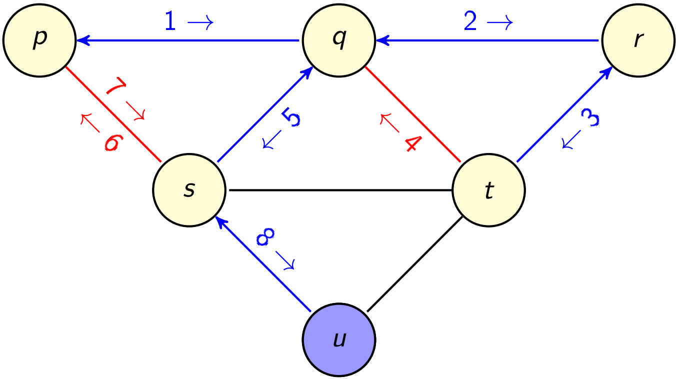

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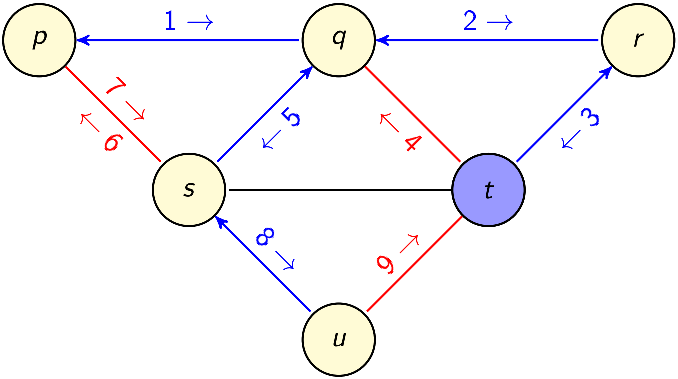

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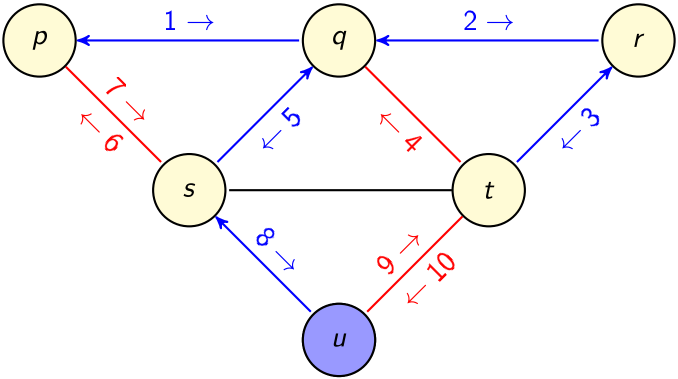

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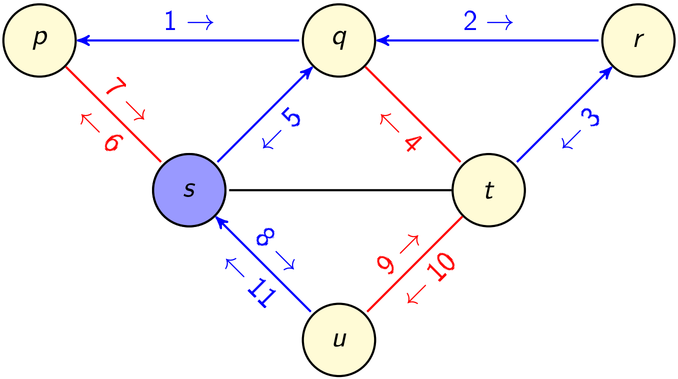

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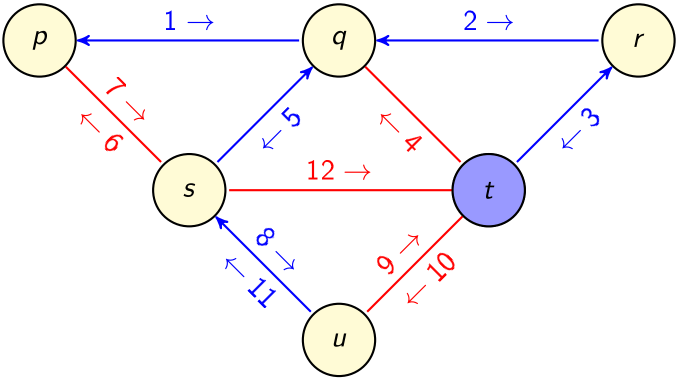

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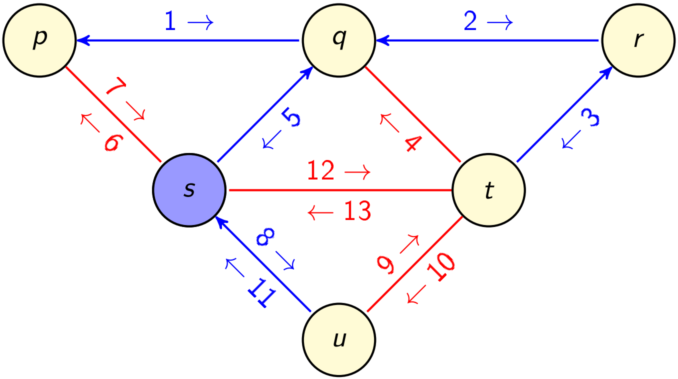

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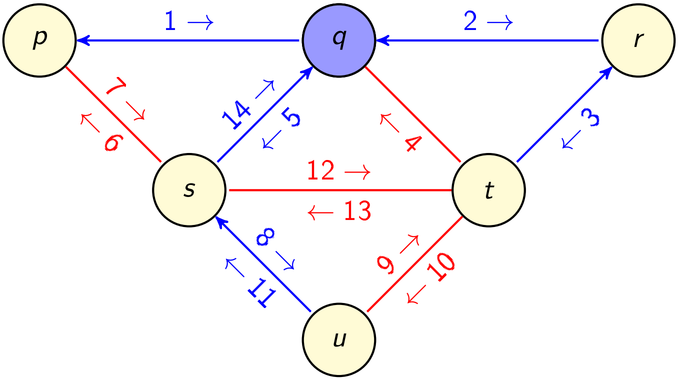

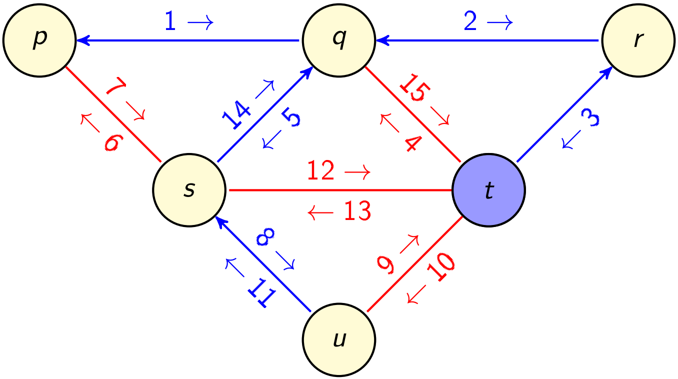
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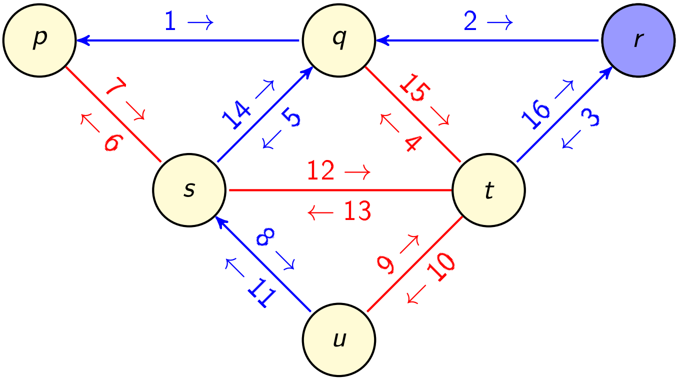

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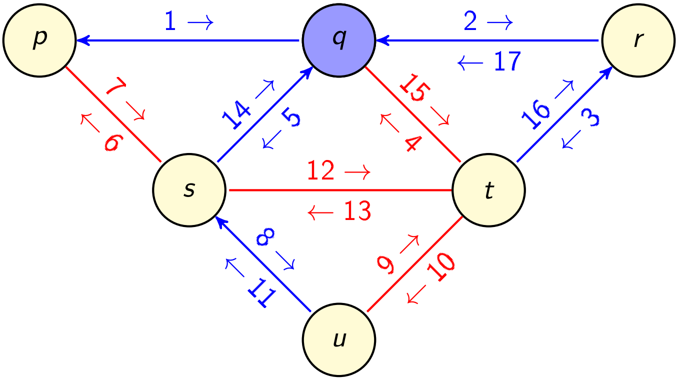

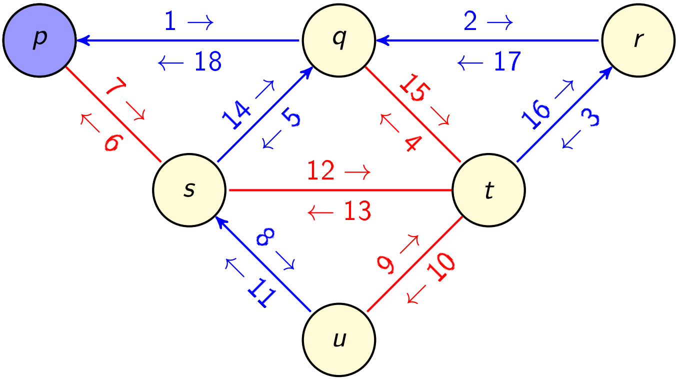
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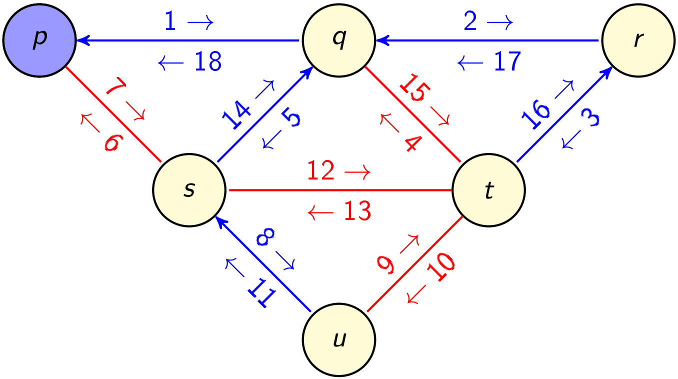

- Every message trace of the execution of a Tarry algorithm is a possible message trace of the execution of an Echo algorithm

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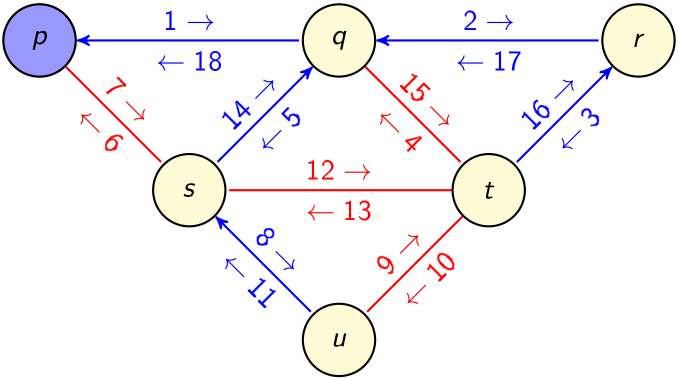


- Every message trace of the execution of a Tarry algorithm is a possible message trace of the execution of an Echo algorithm
- Exercise: Find a message trace of an Echo algorithm that is not the message trace of a Tarry algorithm

Deadlocks

A *deadlock* is what the situation is called if a process is stuck in an infinite wait.

- A *communication deadlock* is where there is a cycle of processes each waiting for the next process in the cycle to send it a message
  - Process p will not send any message until it receives one from q, which will only send it after it receives a message from r, which will only send it after it receives a message from p.
- A *resouce deadlock* is where there is a cycle of processes each waiting for a resource held by another process in the cycle
  - Process p wants to transfer money from account A to account B, has obtained a lock on A and is waiting to obtain a lock on B
  - Process q wants to transfer money from account B to account A, has obtained a lock on B and is waiting to obtain a lock on A

Dealing with Deadlocks

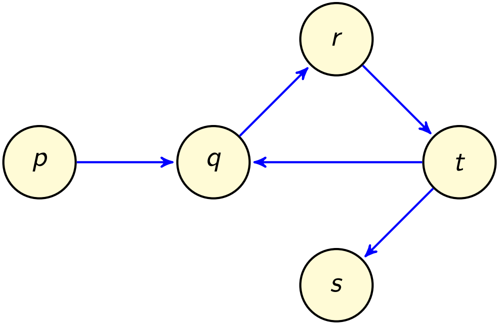
There are essentially 3 strategies for dealing with deadlocks:

- Make deadlocks impossible: Define protocols to ensure that a deadlock can never happen
  - e.g. require a process to obtain all necessary resources simultaneously before proceeding (if any cannot be obtained, release all held resources and try again)
  - Usually impractical and inefficient in distributed systems
- Avoid deadlocks
  - Only obtain resources if the global state ensures it is safe
  - Usually impractical in distributed systems
- Detect deadlocks
  - Detect deadlocks when they occur and break the chain by forcing one or more processes to fail, release their resources and recover

Waits-For Graph (WFG)

Model the deadlock state with a *Waits-For Graph (WFG)*

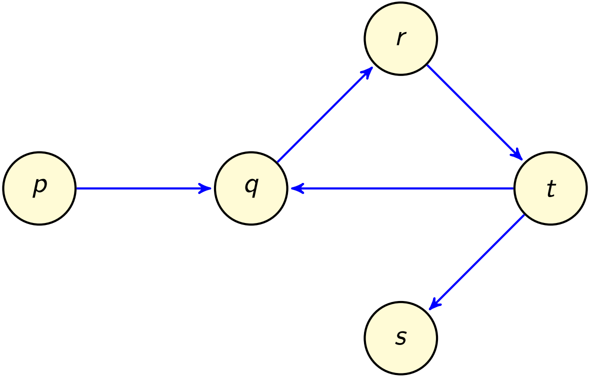
- Directed graph
- Nodes are processes
- Edge from p to q if p is blocked waiting for q to respond or release some resource
- In the simplest model, a cycle in the WFG $\Rightarrow$ deadlock



Deadlock Models

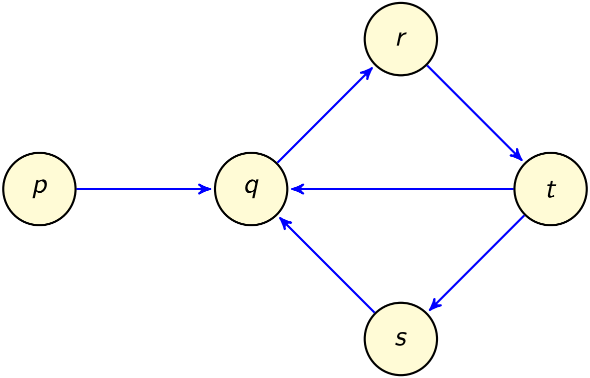
- *Single-resource* model:
  - A process can have at most one outstanding request for one (unit of a) resource
  - Cycle in WFG $\Rightarrow$ deadlock
  - Simplest model
- *AND* model
  - Each process can request multiple resources simultaneously and *all* requested resources must be supplied to unblock
  - Each node is called an *AND node*
  - Cycle in WFG $\Rightarrow$ deadlock
- *OR* model
  - Each process can request multiple resources simultaneously and *one* requested resource must be supplied to unblock
  - Each node is called an *OR node*
  - Cycle in WFG $\not\Rightarrow$ deadlock
  - *Knot* in WFG $\Rightarrow$ deadlock
  - a *knot* is a set of vertices such that every vertex u reachable from a knot vertex v can also reach v

OR Model Example



Cycle but no knot $\Rightarrow$ no deadlock for OR-model

OR Model Example



Knot $\{q, r, s, t\} \Rightarrow$ deadlock for OR-model

More Deadlock Models

- *AND-OR* model
  - Generalisation of both *AND* and *OR* models
  - Each process can request any combination of *AND* and *OR* requests simultaneously and *a set satisfying the requested condition* of requested resources must be supplied to unblock e.g. x and (y or z)
  - No simple graph structure whose presence identifies deadlock
- $\binom{p}{q}$ or q-out-of-p model
  - Equivalent to *AND-OR* model
  - Each process can request from p resources simultaneously and q from these resources must be supplied to unblock
  - An *AND* node is equivalent to a p-out-of-p node and an *OR* node is equivalent ot a 1-out-of-p node.
- *Unrestricted* model
  - No assumptions other than stability of deadlock (once it occurs, it does not release without action to break the deadlock being taken)
  - Only of theoretical interest because of high overhead

Deadlock Detection

Two problems need to be solved to implement deadlock detection in a distributed system:

1. How to maintain the WFG?
2. How to find cycles or knots in the WFG?

To be correct, a deadlock detection algorithm must guarantee:

1. *Progress:* All existing deadlocks must be found in finite time
   - Once all wait-for edges of a deadlock have formed in the WFG, the algorithm should be able to detect the deadlock without having to wait further
2. *Safety:* The algorithm should not report deadlocks that do not exist (*phantom deadlocks*)
   - No global memory or shared clocks $\Rightarrow$ processes have only partial knowledge of global state
   - $\Rightarrow$ processes may detect cycles in the WFG that never truly existed but which are composed of different parts that did exist in the system at different times
   - Main source of errors in published papers on deadlock detection