- For multiple flows sharing the same link, who allocate the link resource to those flows? (Not a single router, or chromecast) Say two flows share 10 Mbits/s. Then,it could possibly be:
    - 5 Mbit/s + 5 Mbit/s
    - 2.5 Mbit/s + 7.5 Mbit/s
    - 0 Mbit/s + 10 Mbit/s
    - 0 Mbit/s + 5 Mbit/s (this is a collapse)
    - 0 Mbit/s + 10 Mbit/s but every packet is sent twice (throughput 10 Mbit/s but "goodput" 5 Mbit/s, this is also a collapse)
- Maximize total utility
    - $\sum_i U(x_i) \quad s.t. \quad x_1 + x_2 \leq 10$
    - If $U(x) = \log(x)$, this gives $x_1 = x_2 = 5$ because $log(x)$ has diminish return ($log'(x)$ decreases as x increases)
- What happens if a host does not follow the congestion control? (Eventually ISP may regulate the host, but) congestion control is a voluntary restraint.
- Real-life congestion control: we don't know the bottleneck link rate, or how many people are sharing the link. Then, how do we decide what is the "right" speed to send data?
- From last week: Single-flow, single-hop model
    - S(ender) —---------- X(router) —----------- R(receiver) with r = 1 Gbit/s and propagation delay = 1 second
    - The sender sends a datagram, still waiting for the corresponding ackno, where could the datagram be (in the sender's mind):
        - Propagating on the link
        - Waiting at the router queue (bottleneck queue)
        - Could have been received by the receiver, but ackno still on the way back
        - Or the datagram or the ackno is lost/dropped
- Easiest approach of flow-control: window_size.
    - We could have both: 1) receiver's window and 2) "congestion window". The minimum of the two cap the actual window.
    - "Self-clocking": a new byte is sent only after a byte is acked (or judged lost)
    - Wrong window size is okay (see below), but wrong rate would lead to more dangerous situations (e.g. queue overflow).
- How much data can be "on the link"?
    - The BDP (Bottleneck link rate Delay Product): $RTT \ * \ link\ rate$
- The ideal value for window size for one flow
    - If the window size is greater than BDP, packets queue up at routers. (At the steady state, window size - BDP bytes is queued at the bottleneck, not so bad).
    - If the window size is smaller than BDP, the bottleneck link may be idle. (Some part of the link would be wasted, bust still not so bad)
    - With one flow, BDP is the ideal window. Any window less than BDP + max queue size is "no loss" window.
- Say two flows share 10 Mbits/s and RTT = 100ms.

    - One flow, good window ~ 10 Mbit/s * 100ms = 1 Mbit = 100 kByte
    - Two flow, good window: 50 kByte for each flow
- BUT, the “ideal” window is unknown at runtime. How to approximate the right congestion window without knowing: RTT, bottleneck link rate, and number of flows
- Ideas for congestion signals:
    - $\frac{d\, throughput}{d\, cwnd}$
    - (experienced) RTT starts increasing
    - Packet loss