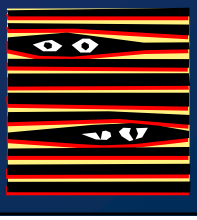
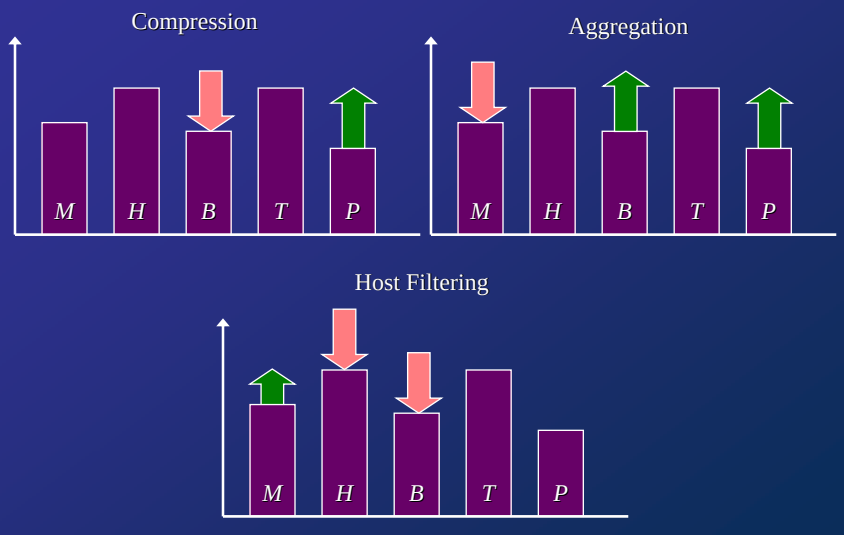
§6.2 Controlling the Visibility of Data

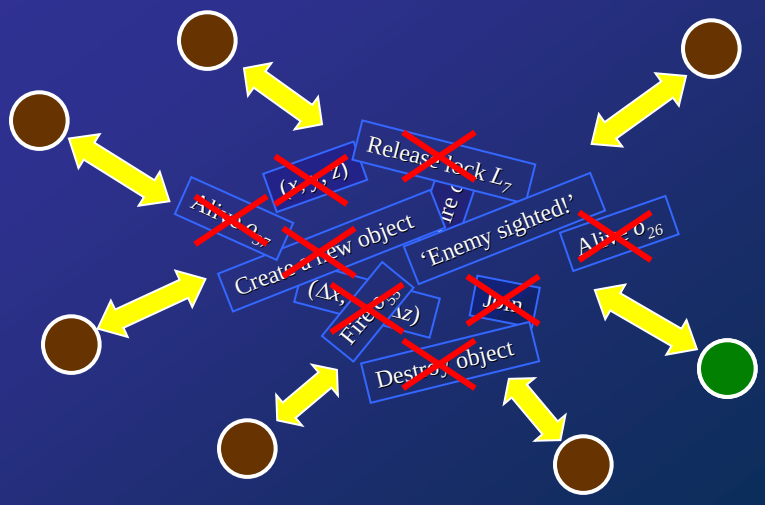
- Area-of-interest filters
  - each host provides explicit data filters
  - filters define the interest in data
- Multicasting
  - use existing routing protocols to restrict the flow of data
  - divide the entities or the region into multicast groups
- Subscription-based aggregation
  - group available data into fine-grained ‘channels’
  - hosts subscribe the appropriate channels



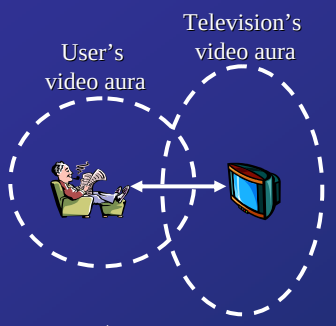
Protocol Optimizations

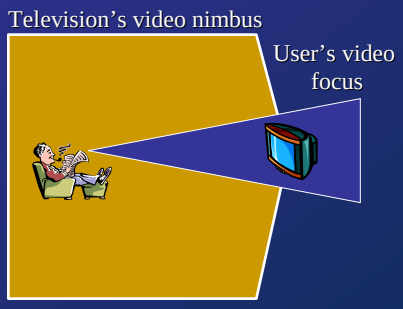


Why to Do Data Flow Restriction?



Awareness and the Spatial Model of Interaction

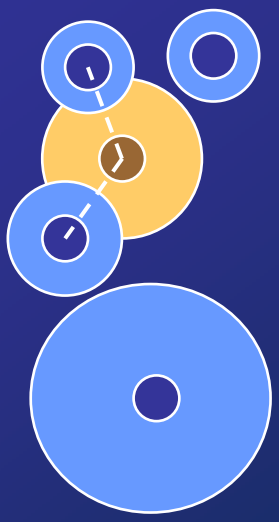




Key concepts:

- *medium*: communication type
- *aura*: subspace in which interaction can occur
- *awareness*: quantifies one object's significance to another object (in a particular medium)
- *focus*: represents an observing object's interest
- *nimbus*: represents an observed object's wish to be seen
- *adapters*: can modify an object's auras, foci, and nimbi

Nimbus-Focus Information Model



- Nimbus: entity data should only be made available to entities capable of perceiving that information
- Focus: each entity is only interested in information from a subset of entities
- Ideally, all information is processed individually and delivered only to entities observing it
  - what about scaling up?
  - processing resouces
  - each packet has a custom set of destination entities ⇒ hard to utilize multicasting
- ⇒ Approximate the pure nimbus-focus model

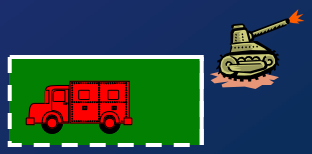
Area-of-Interest Filtering Subscriptions

- Hosts transmit information to a set of subscription managers (or area-of-interest managers, filtering servers)
- Managers receive subscription descriptions from the participating hosts
- For each piece of data, the managers determine which of the subscription requests are satisfied and disseminate the information to the corresponding subscribing hosts
- AOI filtering:
  - restricted form of the pure nimbus-focus model
    - ignores nimbus specifications
  - subscription descriptions specify the entity's focus
  - reduces the processing requirements of the pure model

Subscription Interest Language

- Allows the hosts to expess formally their interests in the NVE
- Subscription description can be arbitrarily complex
  - a sequence of filters or assertions
  - based on the values of packet fields
  - Boolean operators
  - programmable functions

```
(OR
  (EQ TYPE "Tank")
  (AND
    (EQ TYPE "Truck")
    (GT LOCATION-X 50)
    (LTE LOCATION-X 75)
    (GT LOCATION-Y 83)
    (LTE LOCATION-Y 94)
    (EQ PACKET-CLASS INFRARED)))
```



Filtering Subscription-Based System: Example

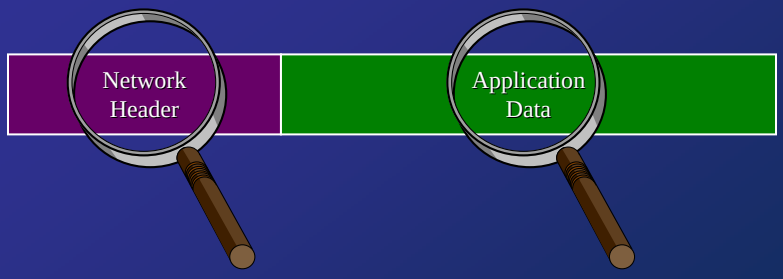
- Joint Precision Strike Demonstration (JPSD)
  - military NVE for training tactical commanders
  - most entities are artificially constructed
  - 6,000 entities, 80 hosts
- Subscription management at each source host
- Each host manages subscriptions from its local entities
- The host sends packets directly to the interested clients using peer-to-peer unicast
- Interest subscriptions
  - logical predicates, operators (equality, ‘within range’)
  - external function modules in a library

When to Use Customized Information Flows?

1. Hosts cannot afford the cost of receiving and processing unnecessary packets
2. Hosts are connected over an extremely low-bandwidth network
3. Multicast or broadcast protocols are not available
4. Client subscription patterns change rapidly
5. No a priori categorizations of data

- Problem when a large number of hosts are interested in the same piece of information
  - customized data streams ⇒ unicast ⇒ the same data travels multiple times over the same network

Intrinsic and Extrinsic Filtering



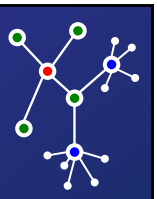
Extrinsic filtering

- Filters packets based on network properties
- Implementation efficient
- Filtering cannot be as sophisticated

Intrinsic filtering

- The filter must inspect the application content
- Can dynamically partition data based on fine-grained entity interests

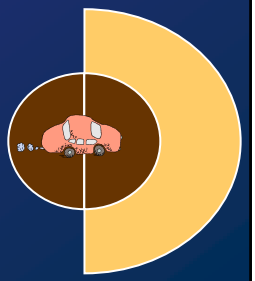
Multicasting



- Transmit a packet to a multicast group (multicast address)
- Packets are delivered to hosts who have subscribed to the multicast group
- Explicit subscription (join group) and unsubscription (leave group)
- A host can subscribe to multiple groups simultaneously
- Transmission to a group does not require subscription
- Challenge: how to partition the available data among a set of multicast groups?
- Each multicast group should deliver a set of related information
- Worst case: each host is interested in a small subset of information from every group ⇒ must subscribe to every multicast address ⇒ broadcast
- Methods:
  - group-per-entity allocation
  - group-per-region allocation

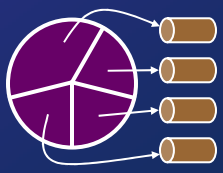
Group-per-Entity Allocation 1 (2)

- A different multicast address to each entity
- Each host receives information about all entities within its *focus*
- Subscription filter is executed locally
- Subscribe to the groups which have interesting entities
- Entities cannot specify their *nimbus*; no control over which hosts receive the information
- Example: PARADISE
  - each entity subscribes to nearby entities
  - control directional information interests
    - nearby entities that are behind
    - nearby and distant entities that are in front



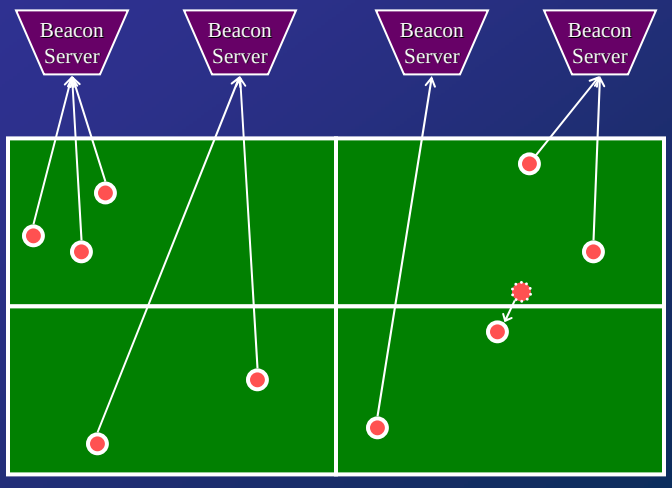
Group-per-Entity Allocation 2 (2)

- Multiple multicast group addresses to each entity
  - position updates
  - infrared data
- Information at a finer granularity
- More accurate focus by group subscriptions



- Hosts need a way to learn about nearby entities
- *Entity directory service* tracks the current state of the entities
  - entity transmits periodically state information
  - directory servers collect the information and provide it to the entities when requested

Beacon Servers

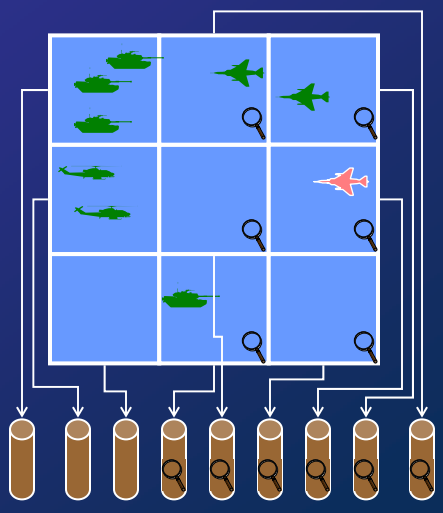


Drawbacks

- Consumes a large number of multicast addresses
- Address collisions become quite probable
- Network routers have to process the corresponding large number of join and leave requests
- Group search induces network traffic
- Network cards can only support a limited number of simultaneous subscriptions
  - too many subscriptions ⇒ 'promiscuous' mode

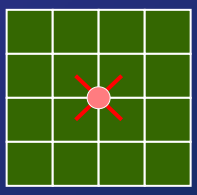
Group-per-Region Allocation

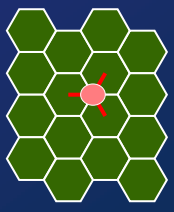
- Partition the world into regions and assign each region to a multicast group
- An entity transmits to groups corresponding to the region(s) that cover its location
- The entity subscribes to groups corresponding to interesting regions
- Entities have limited control over their nimbus but less control over their focus



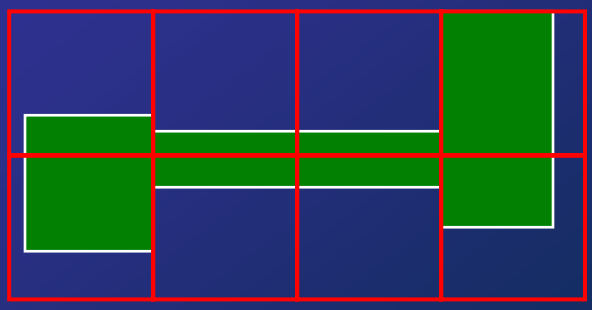
Region Bounds

- An entity has to change its target group(s) throughout its lifetime
  - track the bounds of the current region
  - learn the multicast address of a new region
  - boundaries and addresses assigned to the regions are often static
- In grid-based region assignment there are many points at which multiple grids meet
- Near these corners an entity has to subscribe to several groups



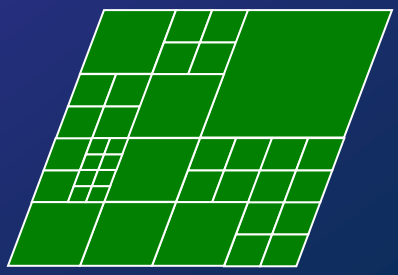


Environment vs. Regular Tessellation

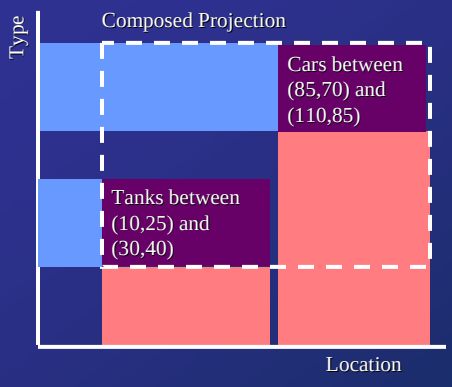


Hybrid Multicast Aggregation

- Balance between fine-grained data partitioning and multicast grouping
- Three-tiered interest management system:
  1. Group-per-region scheme segments data based on location
  2. Group-per-entity scheme allows receiver to select individual entities
  3. Area-of-interest filter subscriptions



Projections

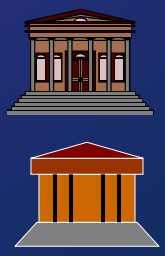


- Projection aggregation server
  - collect data for a projection
  - transmit aggregated packets (projection aggregations)
- Projection composition
  - merge the interest specifications of the component projections

§6.3 Exploiting Perceptual Limitations

- Humans have inherent perceptual limitations





Two approaches to exploit

- Information can provided at multiple levels of detail and at different update rates
- Mask the timeliness characteristics of information