

Motivation



Potential of soft-copy image exploitation systems

- Flexibility and ease of exploitation with electronic light tables
 - Semi-automated tools for mensuration, etc.
- Fusion with other information
 - maps, graphics annotation
 - imagery from other sensors
- Rapid dissemination via electronic networks

Limitations of past approaches

- Expense of custom hardware solutions and lack of COTS technologies to handle large images
- Lack of sufficiently capable archive and communications infrastructure to handle terabytes to petabytes of data
 - Storage technologies
 - Network throughput
 - Processor speeds and I/O bandwidth
 - Scalable image data management and user access software

Motivation (Cont'd)



Key Requirements for an Imagery Archive

- Support a large, diverse community of users with various missions, priorities and access patterns (e.g., geographic, temporal, intelligence problems, etc.)
 - All phases of exploitation
 - Recent image access to historic image access
 - Multi-year archive (10^{15} bytes)
- Provide rapid access to archive
 - Database navigational tools for finding images of interest
 - Interactive access to all images in the archive

Commercial Technologies

- COTS hardware solutions in all key areas are becoming available
- COTS software in some key areas has been developed

Program Goal

- Develop an *interactive, multi-terabyte image archive* and quantify its performance and scalability potential.

What is IMACTS?



“Archive to the Desktop”

- IMACTS is a scalable, distributed, imagery archive and dissemination system supporting an all-soft-copy image exploitation environment.
- Ingests and stores up to 5 terabytes imagery (scalable to petabytes) from multiple sensors
- Provides highly interactive access to image pixel data and metadata
- Distributed architecture supports both local and remote clients

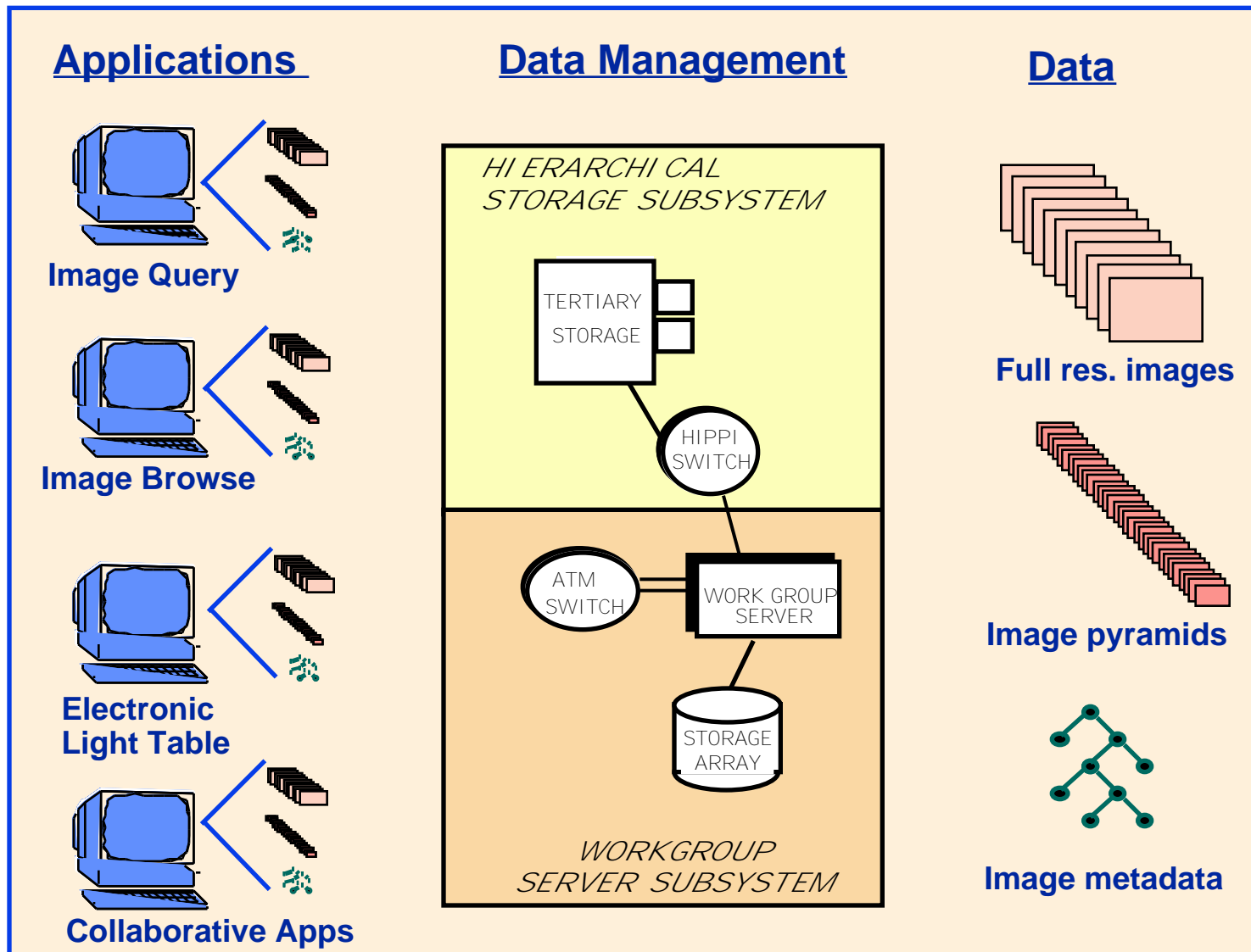
Interactive Services

- *Finding Images* : Powerful query and browse tools support rapid access to archive imagery and metadata
- *Interacting with images*: Rapid, on-demand, access to imagery data using region-of-interest pixel management caching strategies to minimize delays

Interfaces to External Systems

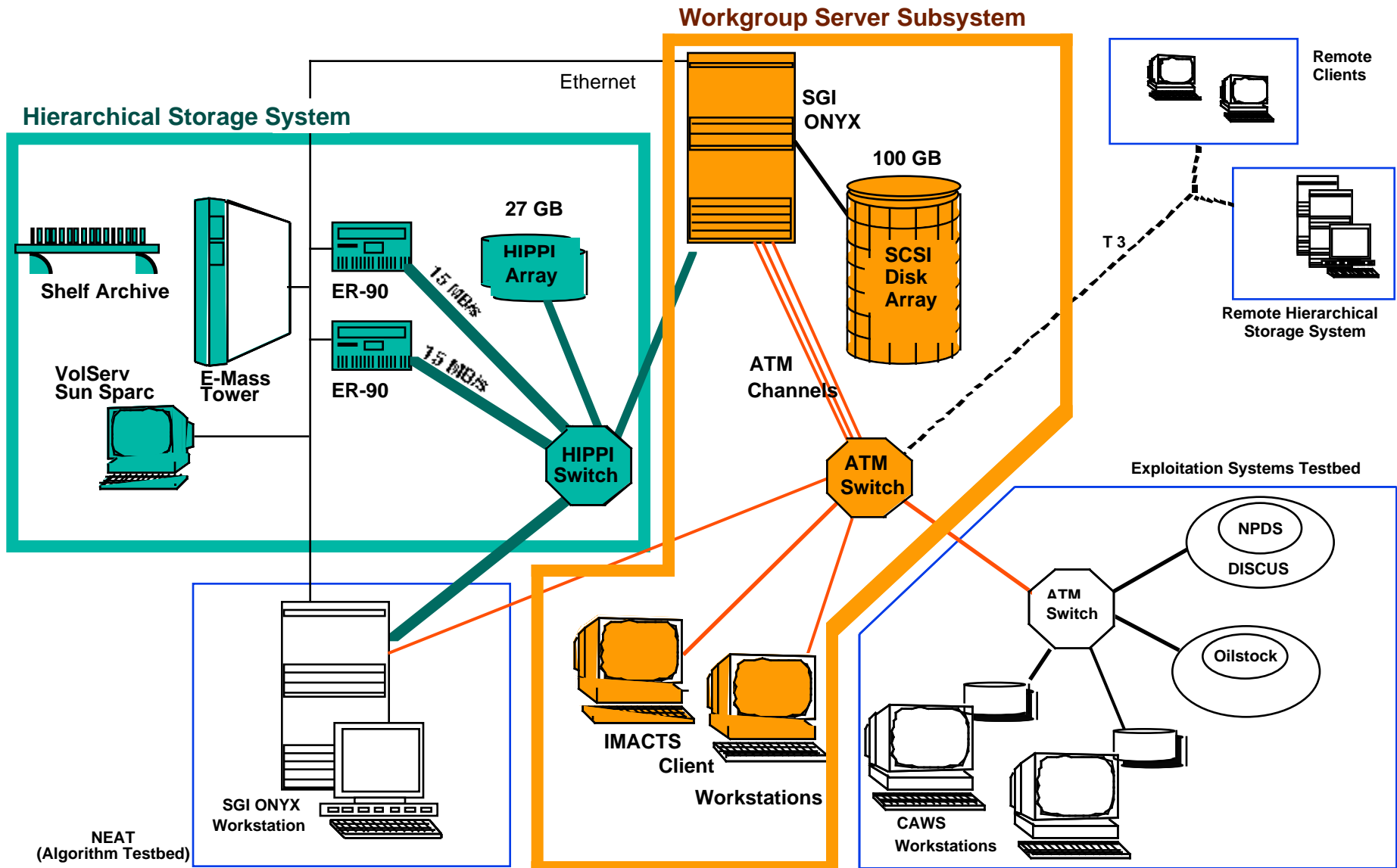
- Electronic light tables (e.g., MATRIX, ELT 7000, OASIS)
- NITF import and export capabilities
- Collateral databases (e.g., NPDS)

IMACTS Concept: “The Virtual Archive”



- Transparent data movement across storage hierarchy
- Distributed, multi-level caching to minimize latencies
- Layered software architecture allows interfaces at various levels:
 - applications
 - database
 - pixel mgt.
 - storage mgt.
- Distributed services for remote users
- Integrated query, browse, and view applications
- Collaborative applications support

IMACTS Hardware Architecture Baseline



Baseline Functional Architecture



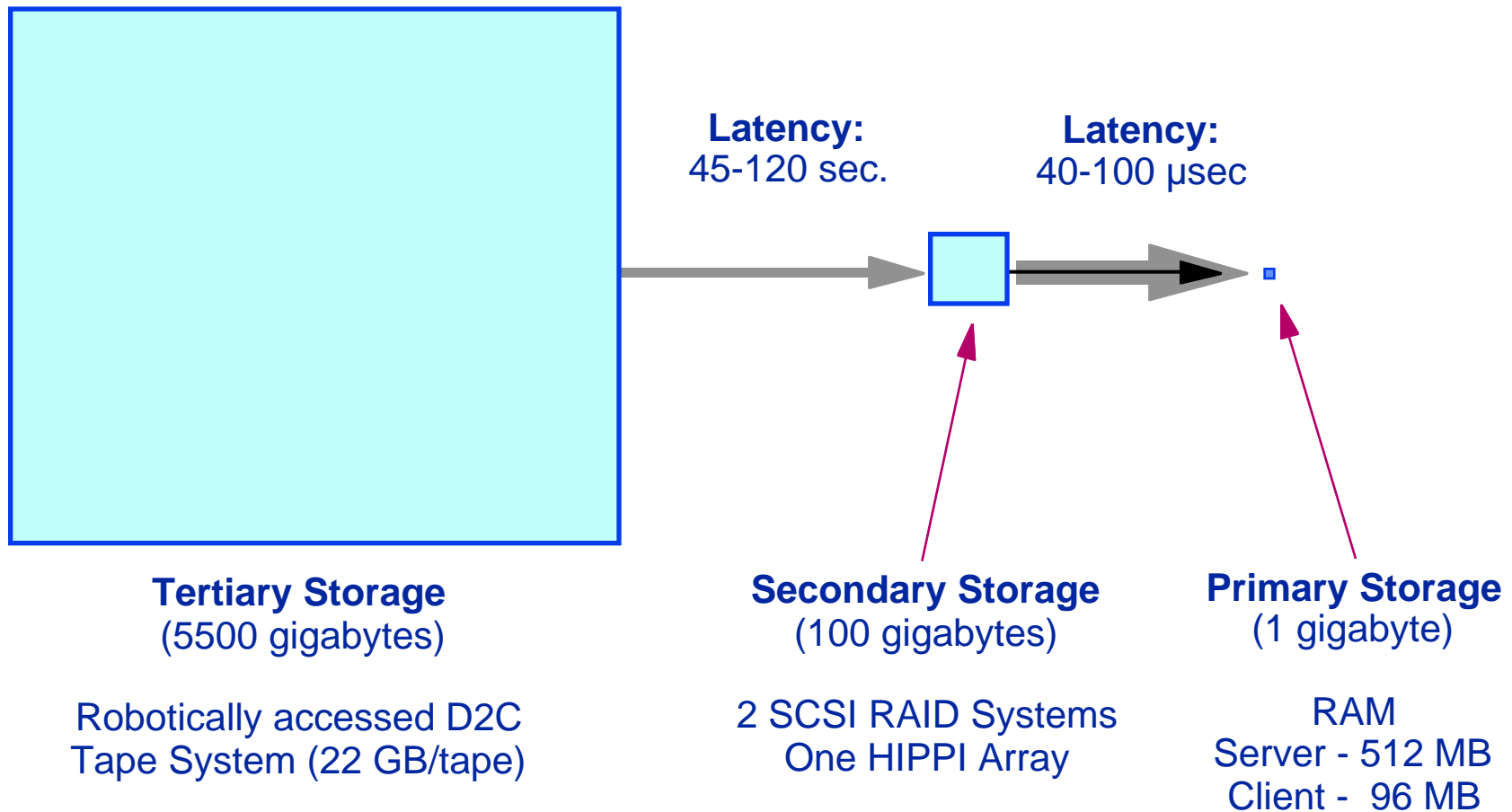
Hierarchical Storage System

- Stores and retrieves all image data – Transparent migration and caching of images across the storage hierarchy (tape and disk)
- Ingests new imagery data – Compresses and formats new imagery

Workgroup Server and Clients

- Support user query, browse, and view functions
- Workgroup server stores browse and metadata
- Workgroup server provides transparent migration of image tiles and metadata to client workstations

IMACTS Storage Hierarchy



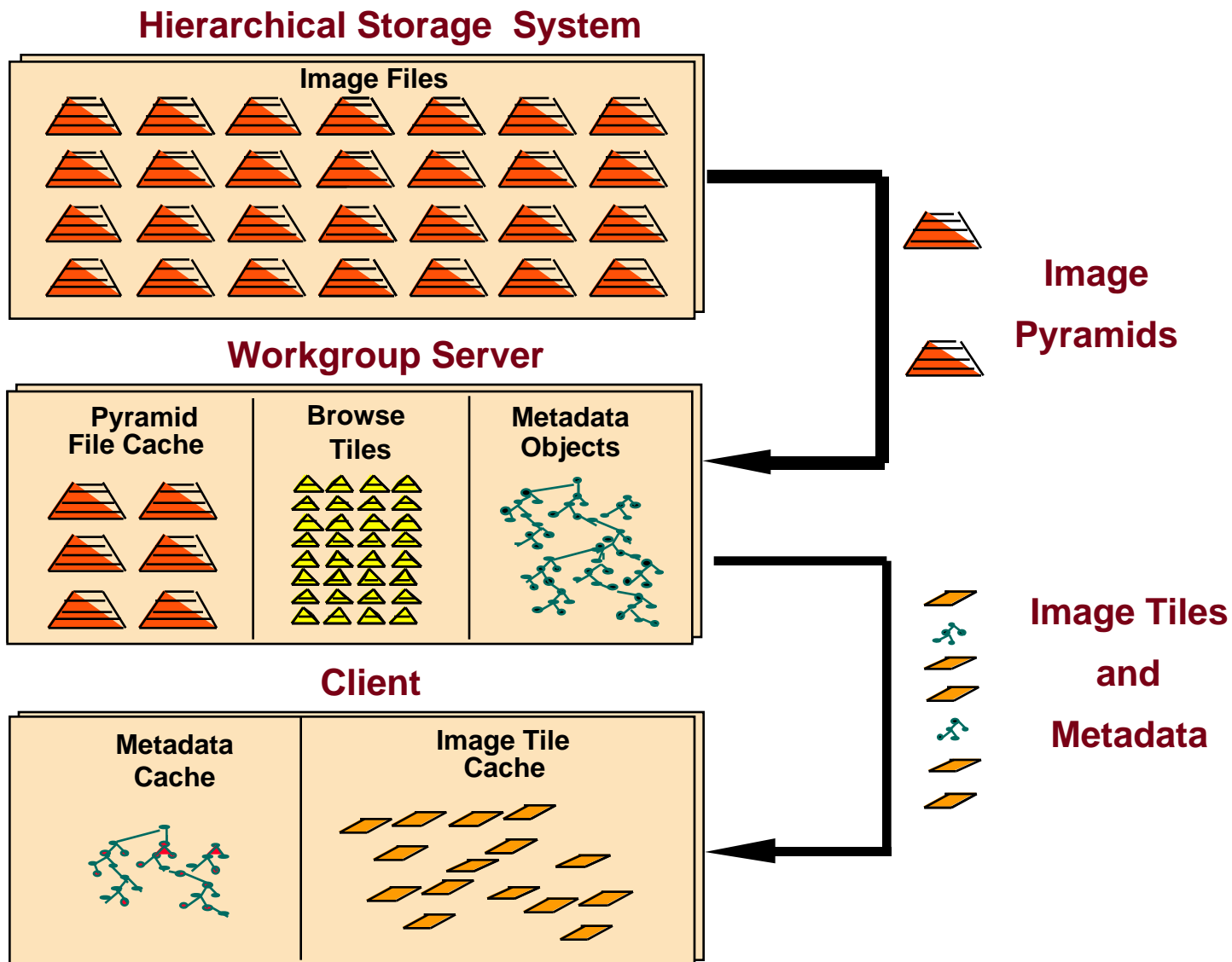
Data Granularity



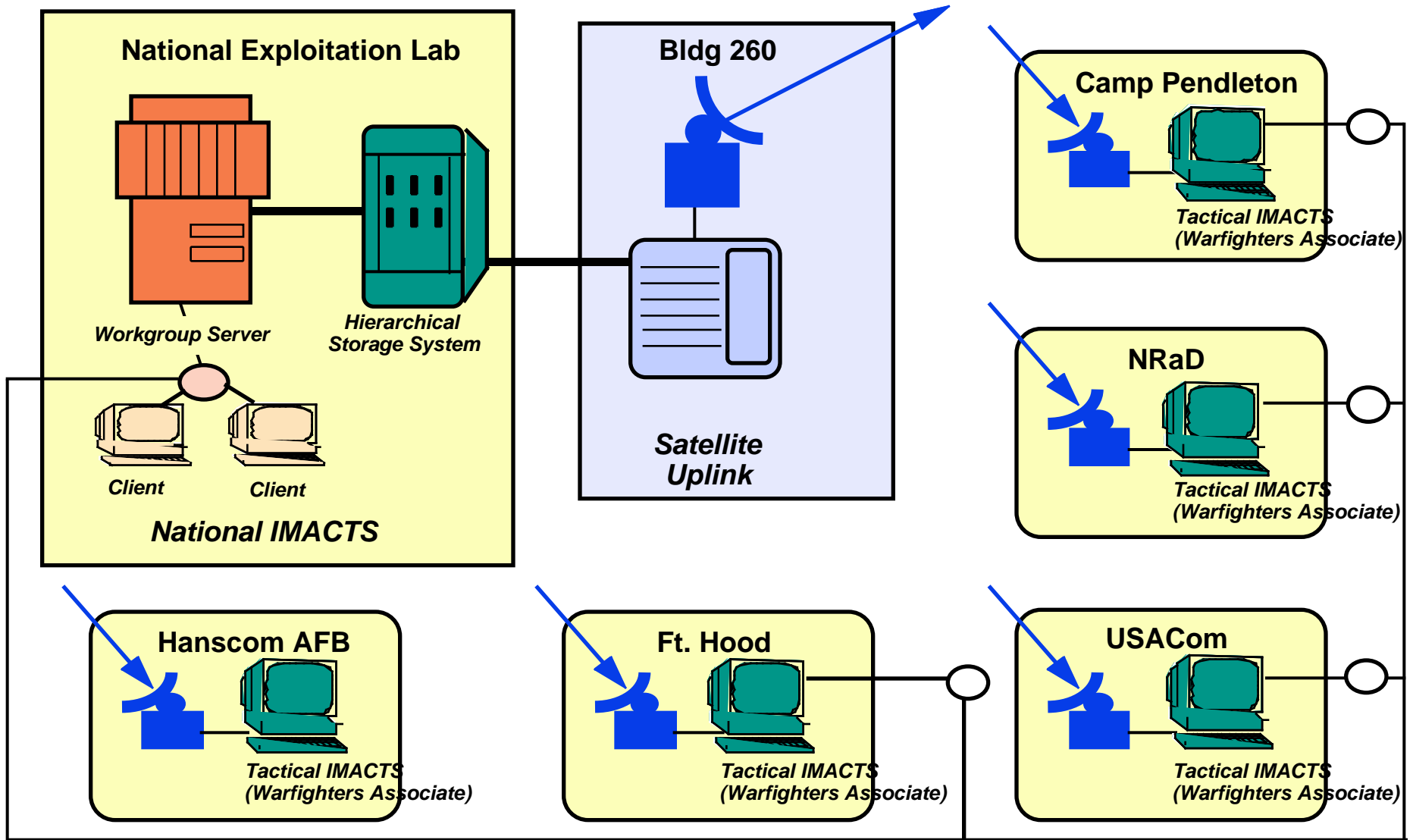
Variable data granularity designed to minimize delays in accessing archive data

- **Image Metadata**
 - Metadata is information about the image
 - Applications pull only relevant metadata to client
 - Data moves from Workgroup Server to Client
 - Lightweight data: 100 – 400 KB per image
- **Image Tiles and Pyramids**
 - Tiles are small sub-regions in an image pyramid
 - System transports only tiles in region of interest
 - Middleweight data: 0.5 – 2 MB per tile
- **Image Files**
 - Largest level of granularity
 - Data moves from HSM to Workgroup Server
 - Heavyweight data: 200 – 2000 MB per image base
 - Pyramid is $\frac{1}{3}$ size of base

IMACTS Software Functions and Caching Model



Distributed IMACTS for Remote Clients JWID '95 Configuration



T-3 Backchannel

IMACTS Support to National and Tactical Users



National users

- Client-server architecture supports users connected via local area network
- Provides integrated, highly interactive query, browse and view tools
- Supports “just-in-time” delivery of pixel data from server to client to minimize delays when viewing images

Tactical users

- Supports all the functions of “national” IMACTS integrated into the Warfighter’s Associate workstation.
- Continuously updated database for interactive query and browse
- Support for both national and tactical imagery sources
- Provides rapid delivery of imagery from national archive via satellite broadcast
 - Transparent image push and image pull from "national" IMACTS archive
 - User-defined profiles specify imagery to be pushed
- Users can request full-frame imagery and/or user-defined image sub-regions

Functional Architecture Extensions for Remote Users



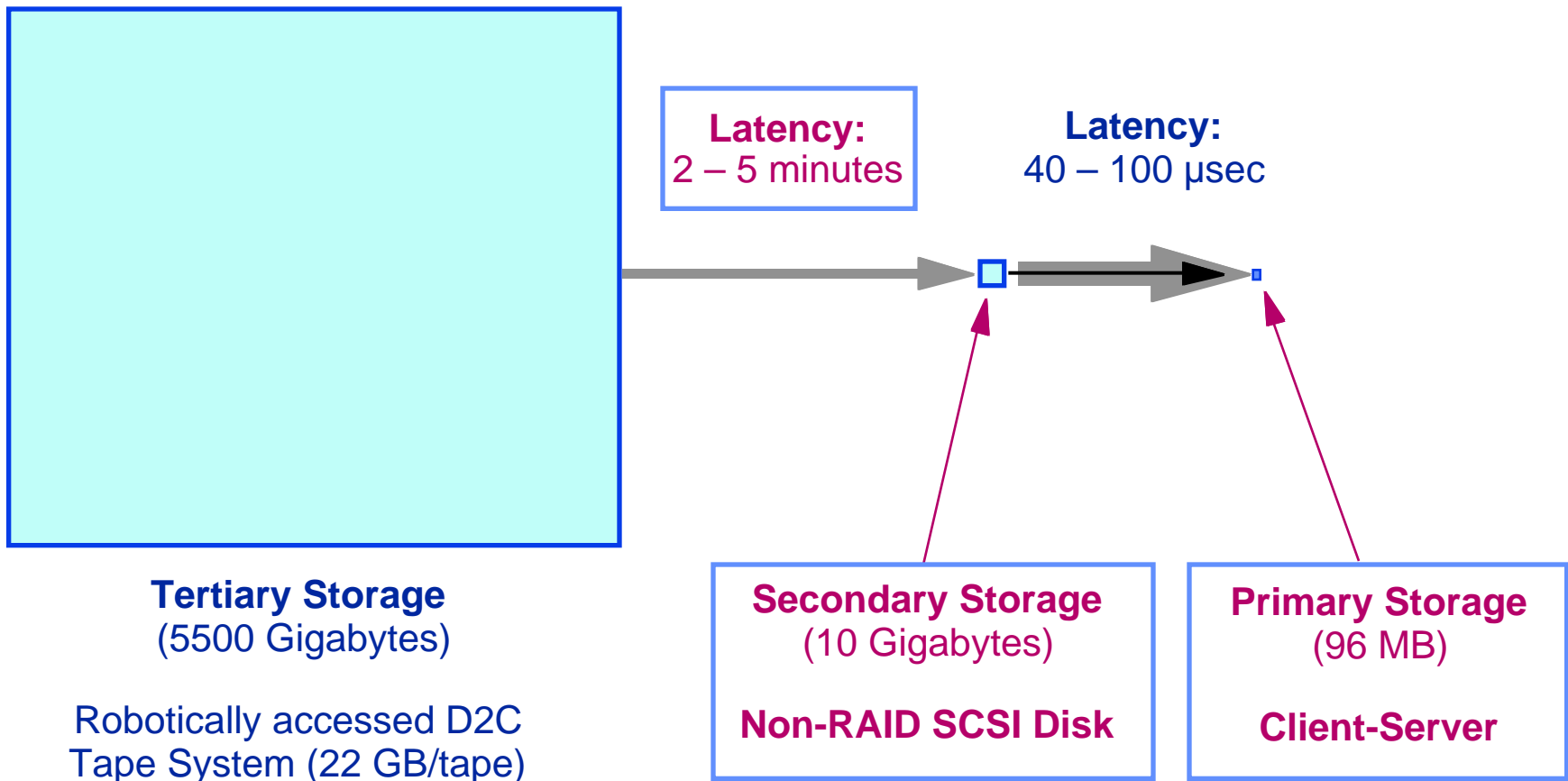
Hierarchical Storage System

- Sends image database and browse data updates to remote users
- Services requests from remote users for full images or sub-images centered around areas of interests (e.g., targets)

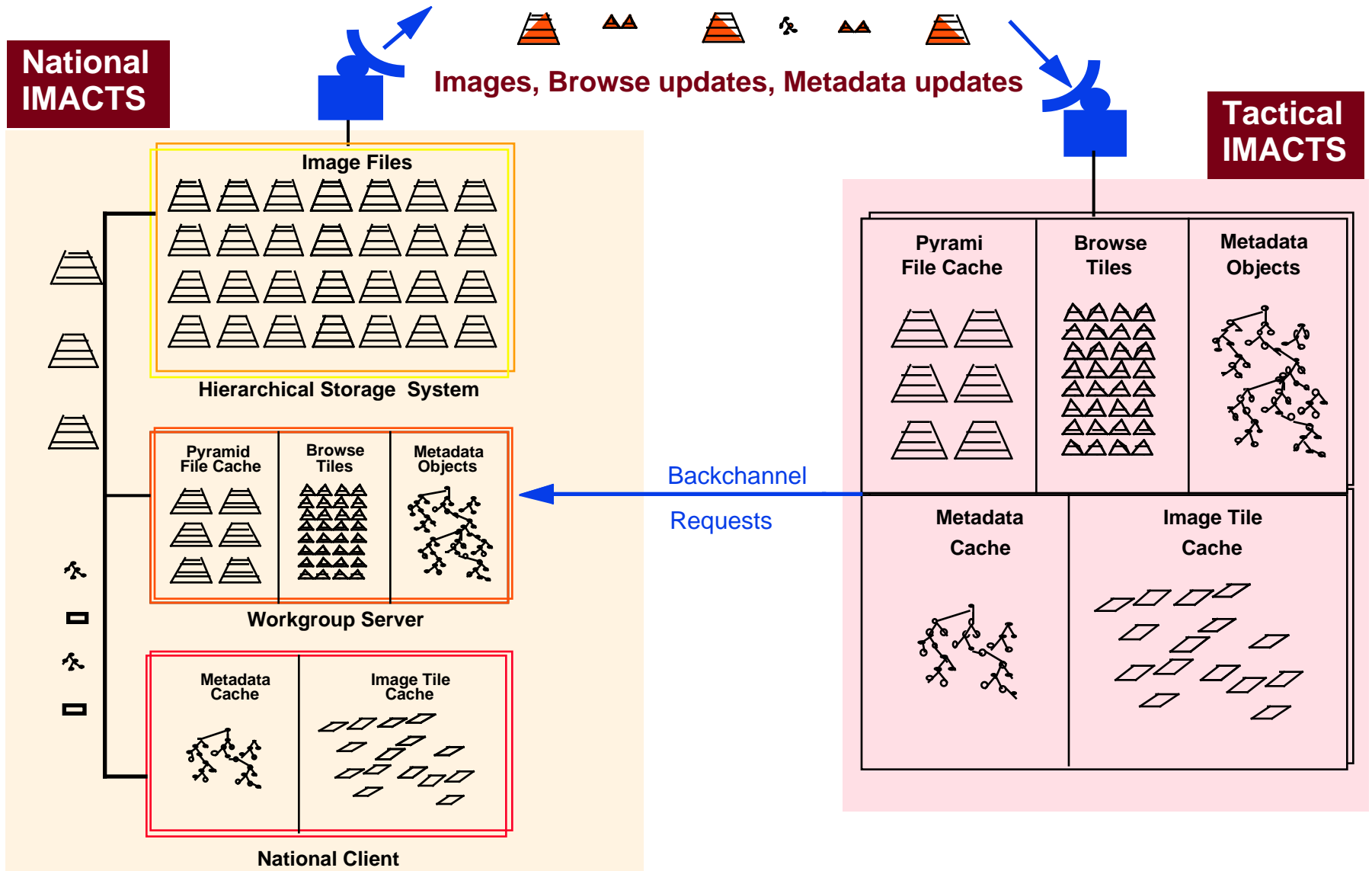
Remote “Tactical” Server-Client

- All metadata and browse data stored in a single workstation
- Tactical user has immediate access to all query, browse data
- Sends requests to National IMACTS for new images or subimages
- Data caching is transparent to user
- Integrated with Warfighter’s Associate

Storage Hierarchy for Tactical IMACTS



Tactical IMACTS Caching Model



IMACTS Software Technology Stack



External Interface

Presents an object interface to external applications and tools

Image Access

Provides integrated, user-level tools for Query, Browse, and View

Metadata Management

Object database manages image metadata including ESD and collateral information from NPDS

Pixel Management

Moves region of interest image pixel data to an application “just in time”

Image Communications

Provides lightweight protocols and fast communication services between servers and clients

Hierarchical Storage Management

Manages transparent movement of images across storage hierarchy (tape and disk)

IMACTS Technologies



Hierarchical Storage Management

Migration Manager

- Manages movement of whole images from tape to disk (caching) and from disk to tape (migration).

Challenge

- Provide transparent and efficient access to any image in the archive – automatically cache (tape to disk) and migrate (disk to tape) images
- Minimize latency of access to images – applications realize the speed of disk and the storage capacity of tape
 - keep highest-priority images nearest to the user application (i.e., on disk)
 - minimize tape latency by grouping related images on the same medium
- Scalable to support petabytes of data

Approach

- Provide reactive and proactive caching and migration policies.
- Utilize static and dynamic (i.e., active query driven) allocation of storage. “Binning” is the proposed mechanism.

Key Idea: Reactive and Proactive Caching



Levels of File Caching

1) Cache recently accessed files

Assumption is that they are likely to be viewed again

2) Pre-fetch files based on application's hints ("anticipatory pre-fetch")

The top few results of a query may be pre-fetched in anticipation of detailed viewing

3) Cache files to disk before they're even asked for

Images can be cached based on user or group profile

When

Once file is requested

Just before file is requested

At ingest

Reactive



Proactive



Key Idea: Dynamically Configurable Storage Bins

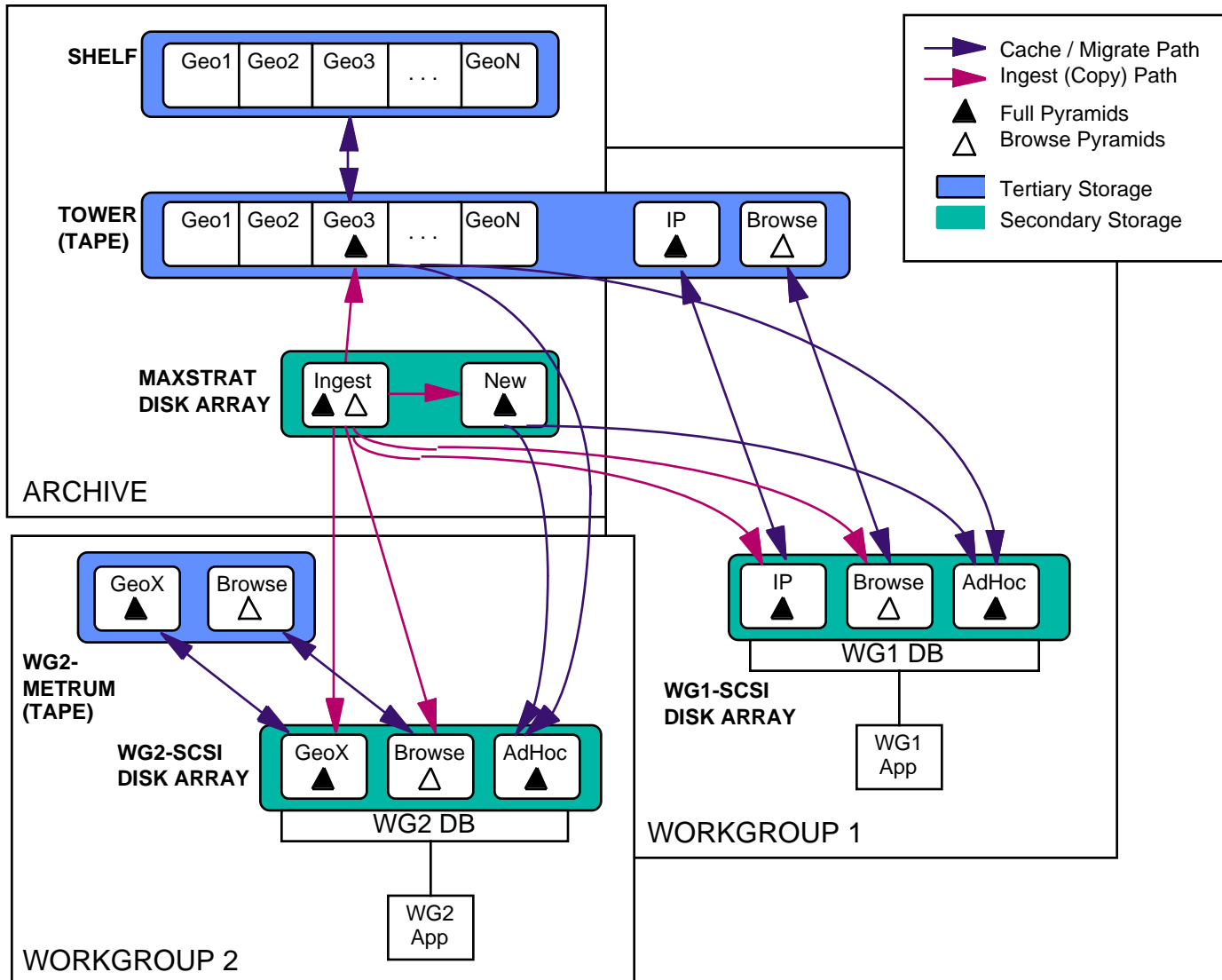
A **Storage Bin** represents a physically and logically contiguous storage partition on tape or disk. Bins provide:

- a way of optimally partitioning the media (both tape and disk)
- a structure to support a flexible caching and migration strategy

Storage bins can be created or deleted by system administrator

- Default binning is by spatial coordinates – Geocells
- Some other kinds of bins
 - Intelligence Problem (IP)
 - Ad Hoc (for high-priority users)

Storage Bins Example



IMACTS Technologies (Cont'd)



Image communications

Network Technology

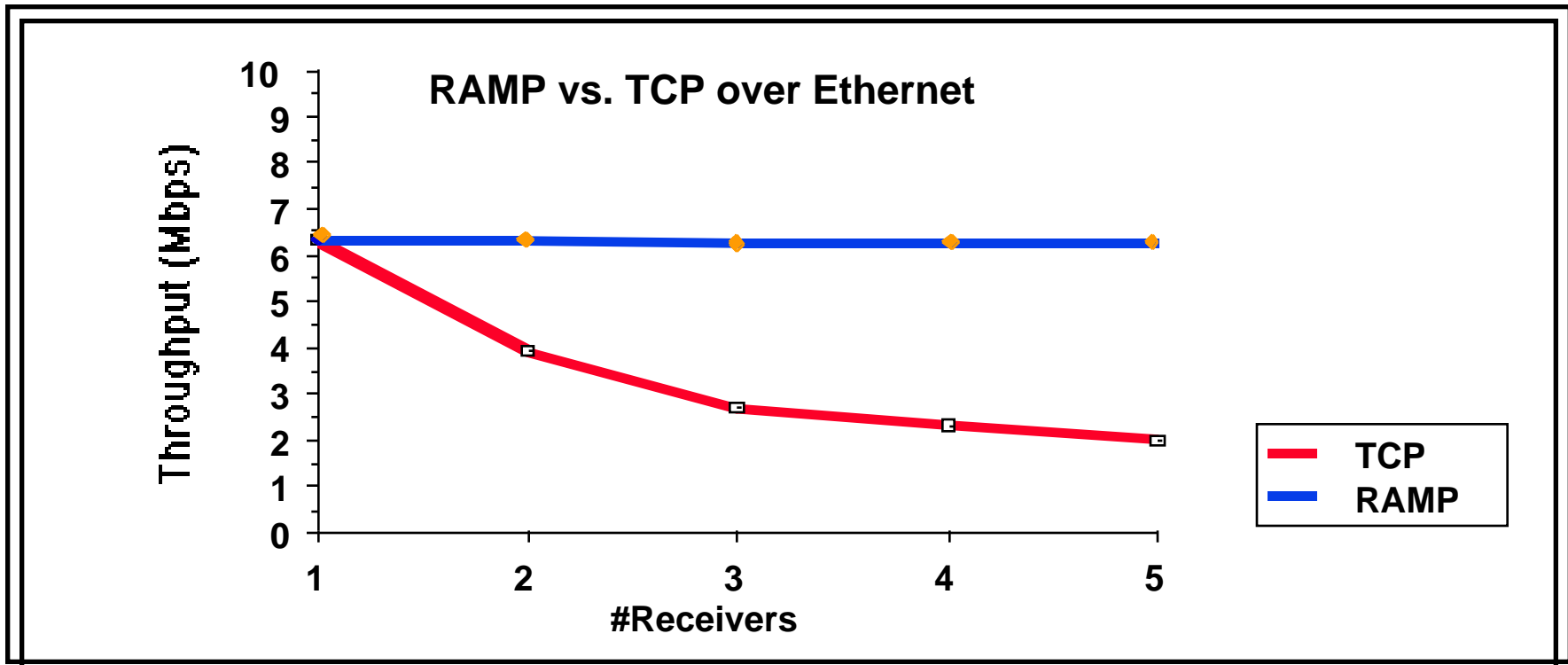
- ATM, RAMP (Multicast transport protocol)

Challenge

- Heterogeneous networks are traditionally a major bottleneck of image based systems
 - Limited bandwidth for image intensive applications
 - Limited scalability
 - Bridges and routers can add additional delays

Traditional “heavyweight

Image Communications RAMP vs. TCP Performance



In multicast mode RAMP maintains linear performance as number of receivers is increased. Multicast important for:

- Image dissemination from HSM to multiple workgroup servers
- Collaborative applications where users share same view of image

IMACTS Technologies (Cont'd)



Pixel Management

Image Tile Caching Technology

- **Array Information Management System (AIMS)**

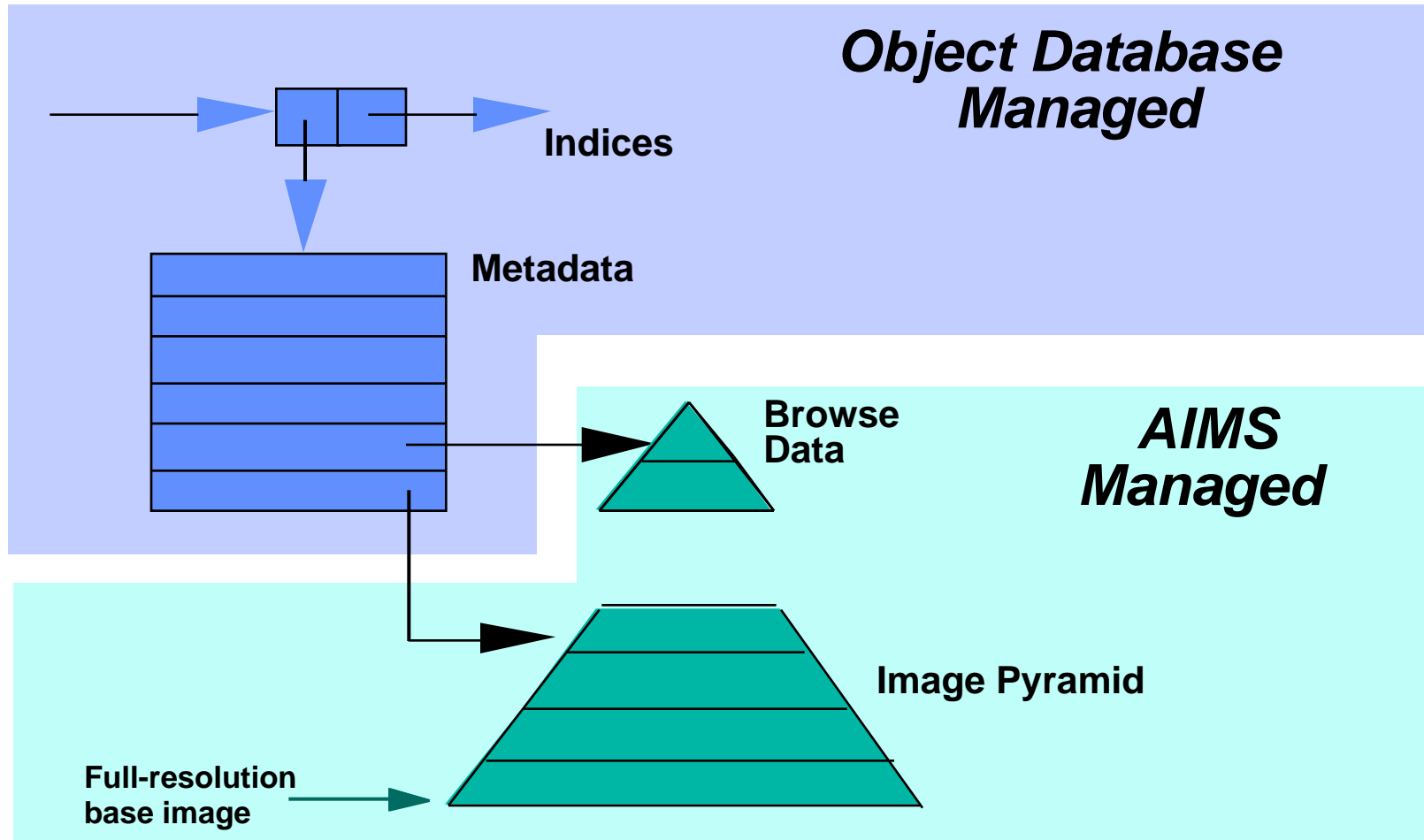
Challenge

- **Delivering “ the right pixels at the right time, just in time”**
 - Moving large images from server to client is inefficient.
 - Wasteful of network and server resources
 - Increases latency – user must wait for entire image to be transferred

Approach

- **Support region-of-interest access to fetch only the pixels needed for display or needed by an application**
 - Images represented as tiled, multi-resolution image pyramids
- **Provide application “hints” to improve performance**
 - Proactive tile fetching during roam for “just in time” display

Pixel Management: Image Pyramids Support Browse and View

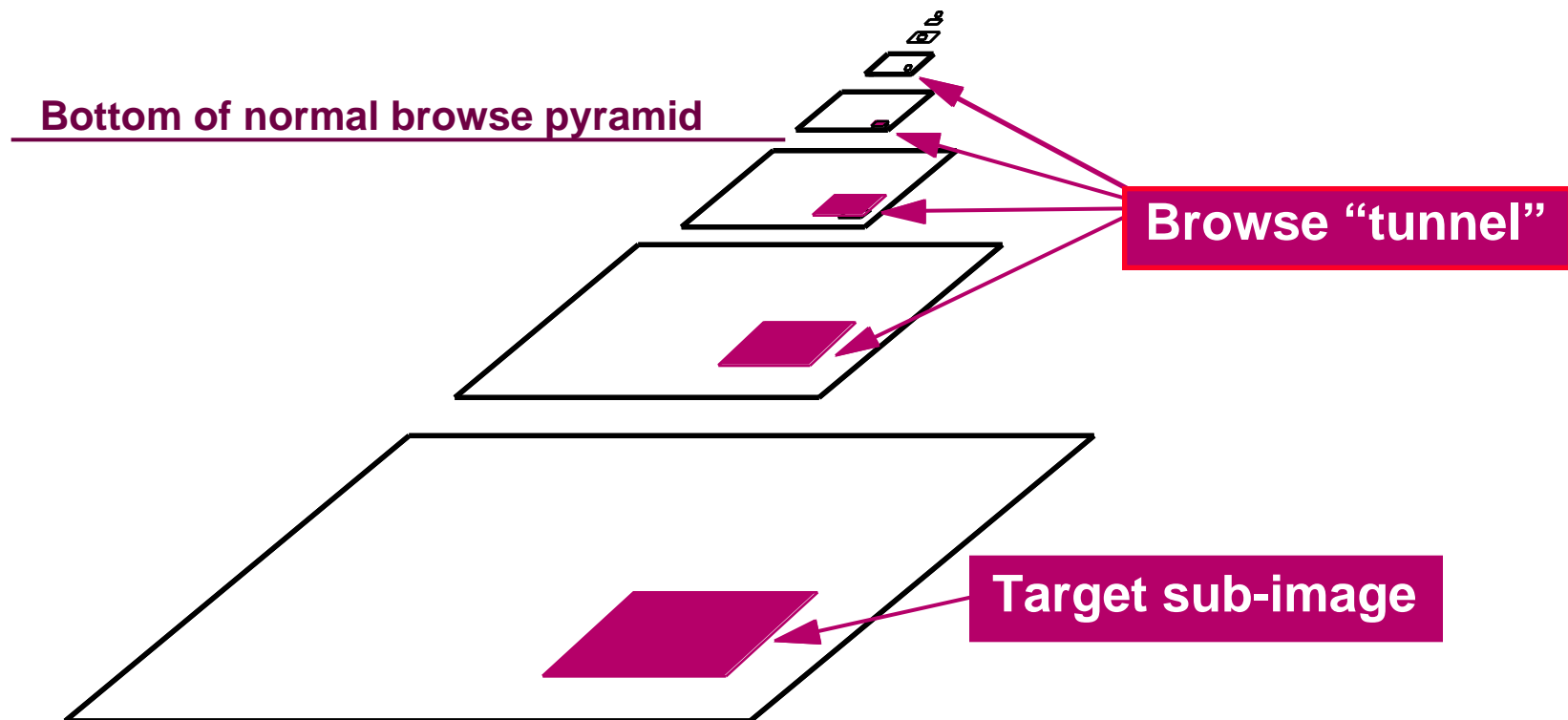


Key Idea: Target Tunneling



Target Tunneling enables the user to create higher-resolution browse pyramids of selected, high-interest areas

- User defines target regions
- System automatically creates associated target image pyramid



IMACTS Technologies (Cont'd)



Pixel Management

Compression Technology

- DPCM, JPEG, Wavelet

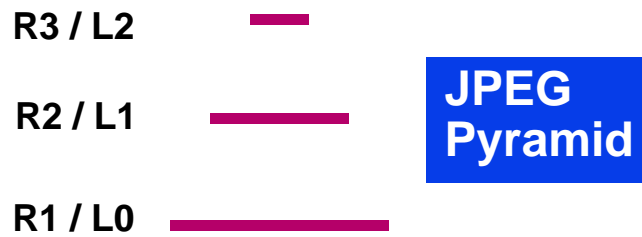
Challenge

- Cost of storage resources can be lowered and the effective throughput of network can be increased through the use of lossy image compression
 - National imagery can be compressed to less than 20 – 30% of its size and retain sufficient image quality for exploitation
- Selection of compression algorithm in an image archive depends on many factors
 - Compression achieved for given image quality
 - Expansion times and where in the architecture the expansion occurs

Approach

- Integrate multiple compression algorithms: DPCM, JPEG, wavelet.
- Investigate interaction of compression services with communications and pixel management services
 - client side vs. server side expansion
 - compression factor for browse imagery

Pixel Management: Image Compression Example



IMACTS Technologies (Cont'd)



Image database

Database Technology

- Object-oriented database

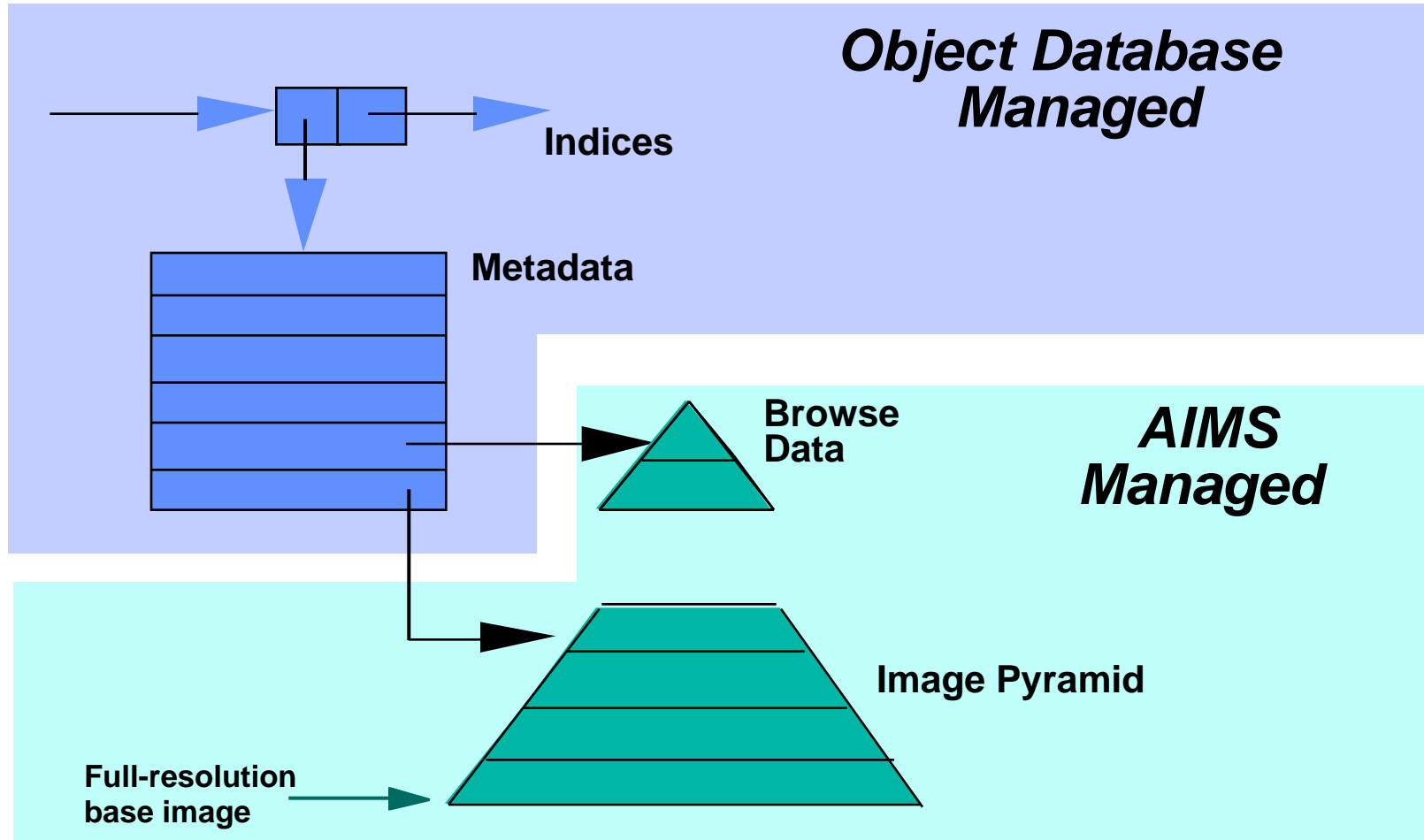
Challenge

- While relational databases have been successfully used to store image metadata, they do not easily support certain types of queries or datatypes that may be important:
 - Navigational queries, e.g., “Find the most recent image to the north of this image”
 - Spatial queries, e.g., “Find images whose targets lie within a bounded region”
 - Span both traditional image metadata and collateral metadata for targets

Approach

- **Implement object-oriented database – ObjectStore**
- **Support structured and free-form (e.g., text reports) metadata**
- **Support associative (e.g., relational) and navigational queries**
- **Incorporate image metadata (ESD from image header) and associated target data (from NPDS)**
- **Explore distributed database and database scalability issues**
- **Compare object and relational-object hybrid**

Image Database



Key Idea: Navigational Query



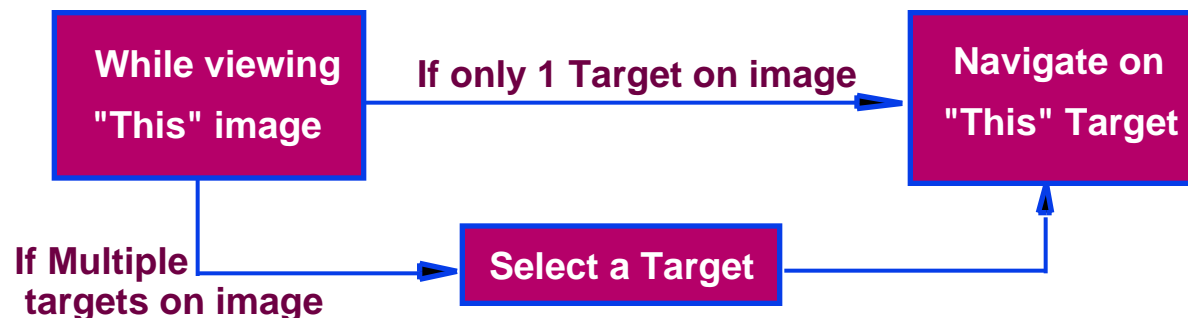
“Navigational” queries provide a mechanism to rapidly access *related* images without explicitly querying the database

For example, while viewing a particular image, users may access other images covering the same target. In particular

- A reference image (of “this” target)
- A previous image (of “this” target)
- The newest image targets related to “this” target

Object database schema support navigational links (pointers) among related objects.

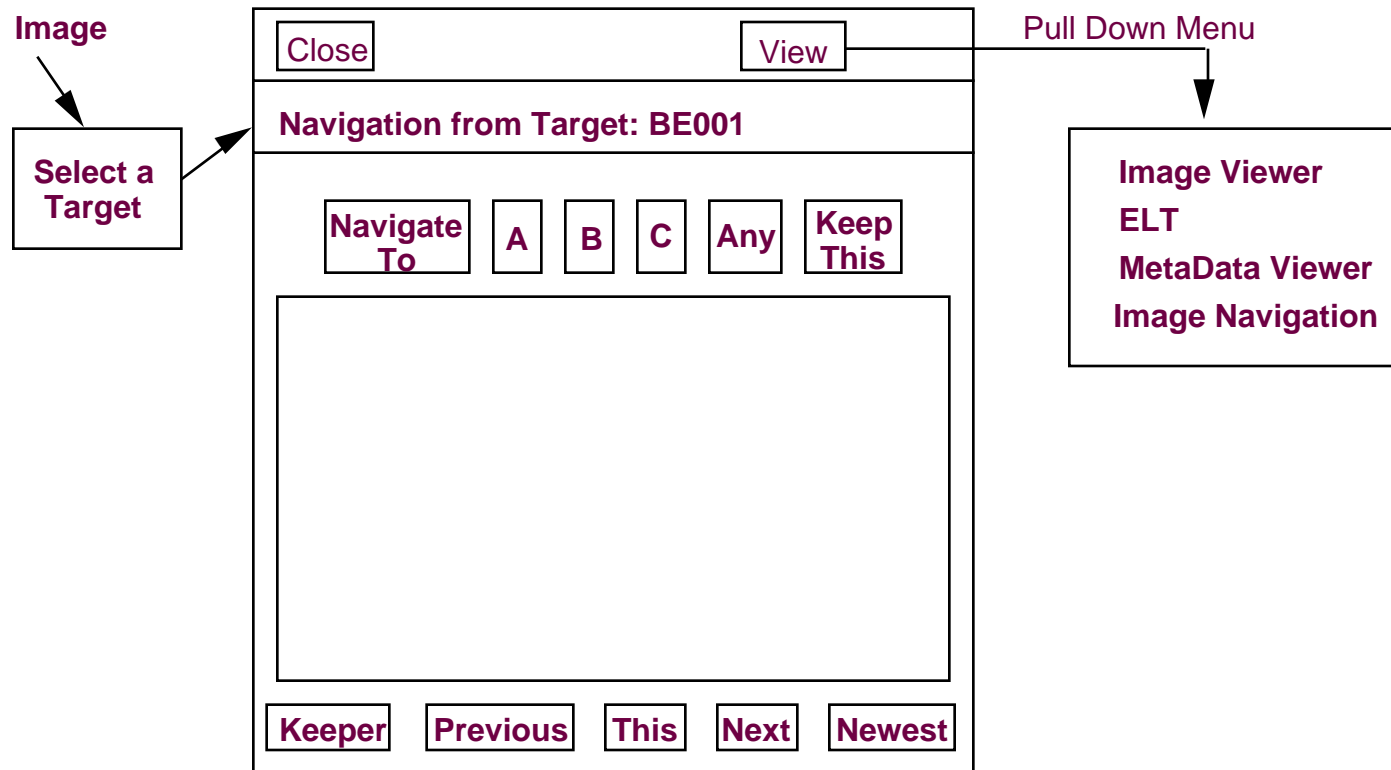
- Analyst can immediately navigate to a new image of a target without having to formulate a new query.



Navigation Panel



Navigation Panel is invoked while browsing or viewing an image
Navigation Panel allows users to access **reference images** and
navigate in **time** (e.g., previous, next, most recent)



IMACTS Technologies (Cont'd)



Image Access

User Tools

- Database Query, Browsing of Query Results, and Viewing of Images

Challenge

- Effective access to thousands to millions of images requires integrated tools for image query, browse, and view.
 - Fast, easy methods to specify queries
 - Permit successive refinement of query to cull query results
 - Integration with browse and view tools

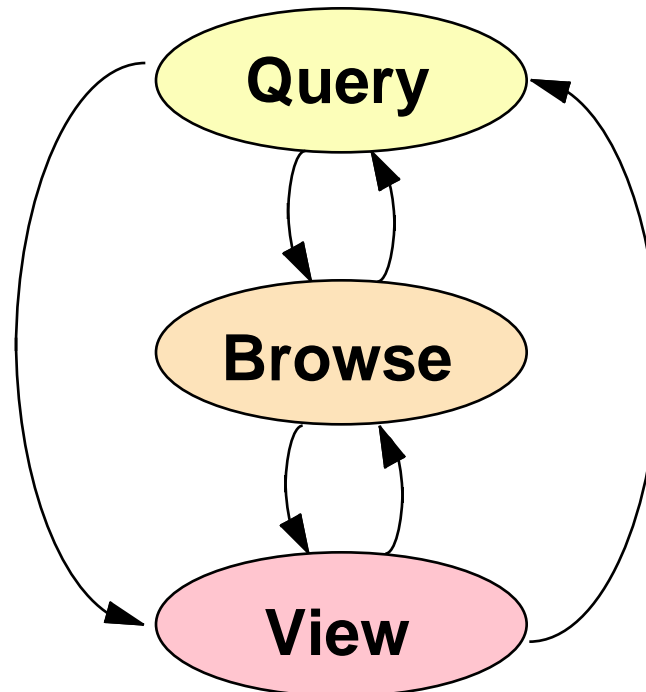
Approach

- Database query tools
 - Forms based interface for normal query
 - Oilstock GUI for spatial query
- Form-based and Graphical Query environments
 - Listing, Flipbook and Montage Browsers
 - Fast image viewer and electronic light table
 - OASIS ELT
- All tools will be fully integrated

Integrated User Tools: Query, Browse, and View



An interactive process involving these cycles:



User Tools (cont'd)



INSERT SCREEN DUMPS OF USER TOOLS

IMACTS Technologies (Cont'd)



External Interface

Interface Technology

- Object-oriented external interface – DISCUS

Challenge

- Provide access and interoperability between IMACTS and other GOTS or COTS packages.

Approach

- Develop DISCUS compliant IMACTS external interfaces – utilizes a commercial object request broker to provide interoperability between IMACTS and other DISCUS compliant applications
- Full support for AIMS hierarchical tile-based access – this work will be accomplished in part by the ARPA ImNet Program
- **DISCUS Interfaces to NPDS and Oilstock**

IMACTS Software Technologies



External Interface

Interoperability of Object Systems
Based on CORBA ORB standards

DISCUS

Image Access

Query and Browse Tools
Image Viewers

User Tools

Object Database

- Navigational and Associative queries
- Structured and unstructured metadata

ObjectStore

Pixel Management

- Multi-resolution tile access and compression

AIMS

Image Communications

- ATM LAN and WAN
- New transport Level protocol / ATM Reliable Multicast

RAMP

Hierarchical Storage Management

- Image caching and migration across storage hierarchy

Migration Mgr

Storage Device Management

Tertiary storage control

System Server



IMACTS DEMONSTRATION