Processing Large Search Result Sets in Java Internet Applications

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Internet Search Requirements

- There can be a large number of hits (1000's) matching criteria
- Results are displayed 1 page at a time
- PREVIOUS and NEXT Buttons to scroll through pages
- A large number of users may be doing queries at same time

Functional Design Goals

- Return first page as quickly as possible
- PREVIOUS page and NEXT page must also be fast

Performance Goals

- Keep resource load on system to a minimum
- Only retrieve as much data as necessary to satisfy user request

Architecture Goals

- Keep presentation layer separate from data access layer
- Provide Search/Retrieval Interface that encapsulates implementation of Search/Retrieval Layer

Current Alternatives

EJB Finder Method

- Inefficient
- Resource Consumptive

Fetch All Hits Into a Collection Before Displaying First Page

- Slow to show First Page
- Very Resource Intensive (Processing and Memory)
- Users typically only browse through a small number of pages

Re-execute Query for Each Page of Display

- Too slow for expensive queries
- Very resource intensive

Fetch several pages of Hits/ Re-execute Query When More Needed

- Efficient if user only browses first few pages
- Can be expensive if user chooses to scroll through many pages

Internet Search Solution: Architecture

Provide List Handler Interface that Encapsulates:

- Search/Retrieval Implementation
- Data Access Implementation

Interface Must Support a Large Variety of Underlying Implementations

- Retrieval of Data from a Database using JDBC
- Retrieval of Data from non-database datastores

Internet Search Solution: Performance

Provide Efficient Implementation of Generic List Handler Interface

- Handles efficient retrieval of data from a database using JDBC

List Handler Interfaces

DataListHandler

- Handles interaction with client
- Execute search
- Return list of search results

DataList

- Represents list of objects retrieved by search
- Does not extend Java List interface to allow greater flexibility in underlying implementations

DataListIterator

- Traverse and access items in list

List Handler Classes

DataListHandlerImpl implements DataListHandler

DataListImpl implements DataList

- Represents list of all objects retrieved by search

DataListChunk implements DataList

- Represents subset of objects in DataListImpl
- Returned to client to satisfy request to display a page worth of hits

DataListIteratorImpl implements DataListIterator

Interfaces: DataList

```
public interface DataList {

  public DataListIterator iterator()
    throws DataListException;

  public Object get(int index, Object item) throws
      DataListException, IndexOutOfBoundsException;

  public boolean isEmpty() throws DataListException;

  /* Release resources */
  public void close() throws DataListException;
}
```

Interfaces: DataListIterator

```
public interface DataListIterator {

  public boolean hasNext() throws DataListException;

  public Object next(Object obj)
     throws NoSuchElementException,
       DataListException;

}
```

Interfaces: DataListHandler

```
public interface DataListHandler {

  public DataList getListChunk(int startIndex,
    int count) throws DataListException;

  public boolean elementExists(int index)
    throws DataListException;

  /* Release resources */
  public void close() throws DataListException;

}
```

Class: DataListImpl implements DataList

- Implements a DataList that represents the entire collection of hits that satisfy a user search request

Class: DataListChunk implements DataList

- Implements a DataList that represents a subset of DataListImpl that is returned to display a page worth of hits
- Returned by DataListHandler.getListChunk method

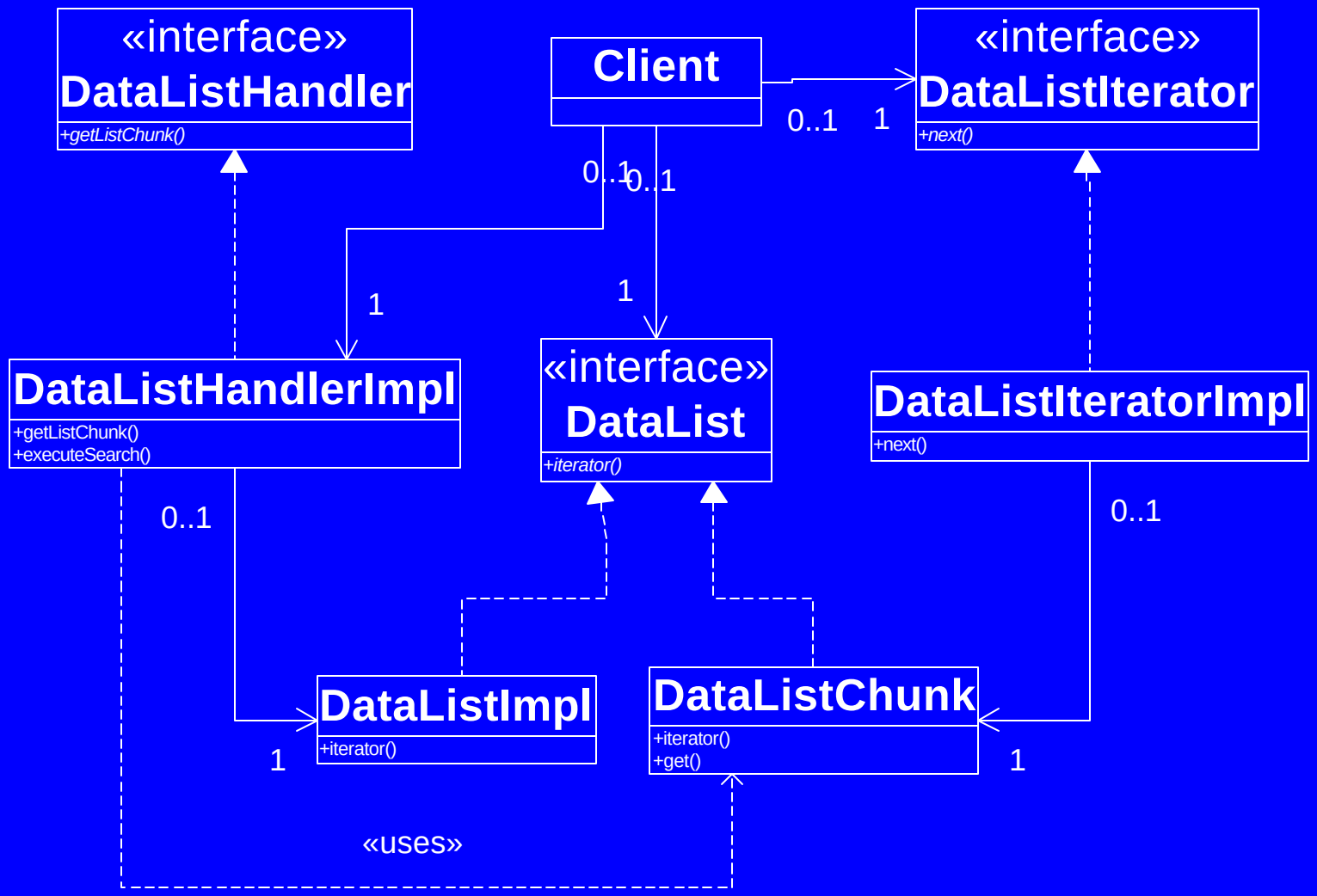
Class: DataListHanderImpl implements DataListHandler

- Executes user search request
- Creates a DataListImpl instance
- Stores search results in DataListImpl instance
- Satisfies getListChunk method request by creating a DataListChunk instance that represents a subset of DataListImpl and returning it

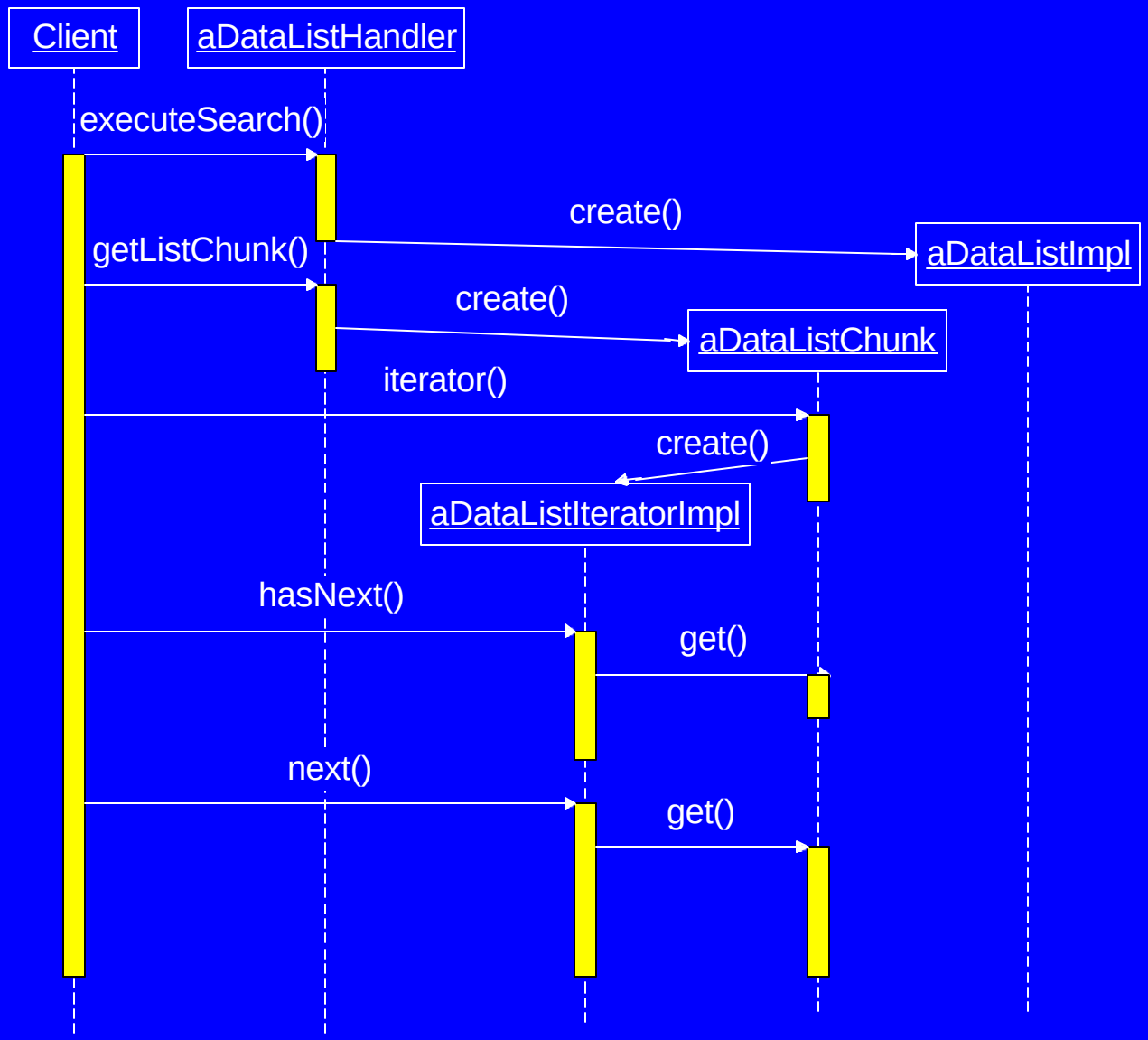
Class: DataListIteratorImpl implements DataListIterator

- Interacts with DataList instance to traverse and access the items in the DataList Collection

Data List Handler Class Diagram



Data List Handler Sequence Diagram



Strategy to Achieve Efficient Retrieval of Large Search Sets In RDBMS

Keep database connection open across requests

- Other strategies open and close a connection for each request

Fetch only as many rows as necessary to return a page of data to client

- Make use of Scrollable ResultSets in JDBC 2.0 Spec

JDBC 2.0: Scrollable ResultSet

New Option When Creating Statement Objects

- ResultSet Type

JDBC 2.0: Result Set Type

TYPE_FORWARD_ONLY (Default, JDBC 1.0 behavior)

- ResultSet is not scrollable
- Fetch forward only

TYPE_SCROLL_INSENSITIVE

- ResultSet is scrollable
- Fetch forward and backward
- Position to absolute or relative row in ResultSet

TYPE_SCROLL_SENSITIVE

- ResultSet is scrollable like TYPE_SCROLL_INSENSITIVE
- Rows changed and committed by other users visible as you scroll

JDBC 2.0 New ResultSet Cursor Positioning Methods

- public void previous()
- public boolean absolute(int index) – Positions to an absolute row number
- public void beforeFirst()
- public void afterLast
- public void first()
- public void last()

JDBC 2.0: New ResultSet Cursor Informational Methods

- public int getRow() – Returns current row number
- public boolean isBeforeFirst()
- public boolean isAfterLast()
- public boolean isFirst()
- public boolean isLast()

JDBC 2.0: Result Set Type Example

```
Statement stmt = conn.prepareStatement(
  "select id, descr from product " +
   "where descr like '%'||upper(?)||'%' order by id",
  ResultSet.TYPE_SCROLL_INSENSITIVE,
  ResultSet.CONCUR_READ_ONLY);

stmt.setString(1,keywords);
ResultSet rs = stmt.executeQuery();

boolean success = rs.absolute(10); // position to 10th row
String id = rs.getInt(1);

rs.previous(); // position to previous row (9th row)
id = rs.getInt(1);
rs.last();  // position to last row
```

Oracle Implementation of a Srollable ResultSet

- Rows are fetched from the database in the forward direction only
- As rows are fetched they are stored in a client-side memory cache maintained by the JDBC driver
- Requests to scroll to a row that has already been fetched from database is satisfied by accessing row in local memory cache.
- Positioning to rows already fetched is very efficient

Strategy: Efficient Implementation of DataList Interfaces

- Keep Database Connections open across Http Requests
- Use JDBC 2.0: Scrollable ResultSets
- Fetch rows only one page at a time

DataList Interface Implementation

- Do not provide direct implementation of DataList Interfaces
- Provide another set of Interfaces that extend DataList Interfaces
- These interfaces are used for DataList implementations that generate search result sets from database queries using JDBC
- Other implementations of DataList might access non-database data stores

JDBC Database Access DataList Interfaces

- ResultSetDataList extends DataList
- ResultSetRowMapper
  - No counterpart in DataList interfaces

JDBC Database Access DataList Classes

- ResultSetDataListImpl (DataListImpl) implements ResultSetDataList
- ResultSetDataListChunk (DataListChunk) implements ResultSetDataList
- ResultSetIterator (DataListIteratorImpl) implements DataListIterator

Interface: ResultSetDataList

```
public interface ResultSetDataList extends DataList {

  public boolean hasNext() throws SQLException;

  public void beforeFirst() throws SQLException;

  public boolean absolute(int index)
    throws SQLException;

  public boolean elementExists(int index)
    throws SQLException;
 }
```

Class: ResultSetDataListImpl implements ResultSetDataList (extends DataList)

- Implements a DataList as a virtual collection that represents the entire result set of a client query
- Contains a scrollable JDBC ResultSet object
- The underlying scrollable JDBC ResultSet is the real collection (also implemented as virtual)
- Implementation of scrollable ResultSet defers fetching of rows until cursor is positioned on the row
- Overhead of fetching all hits up front is avoided

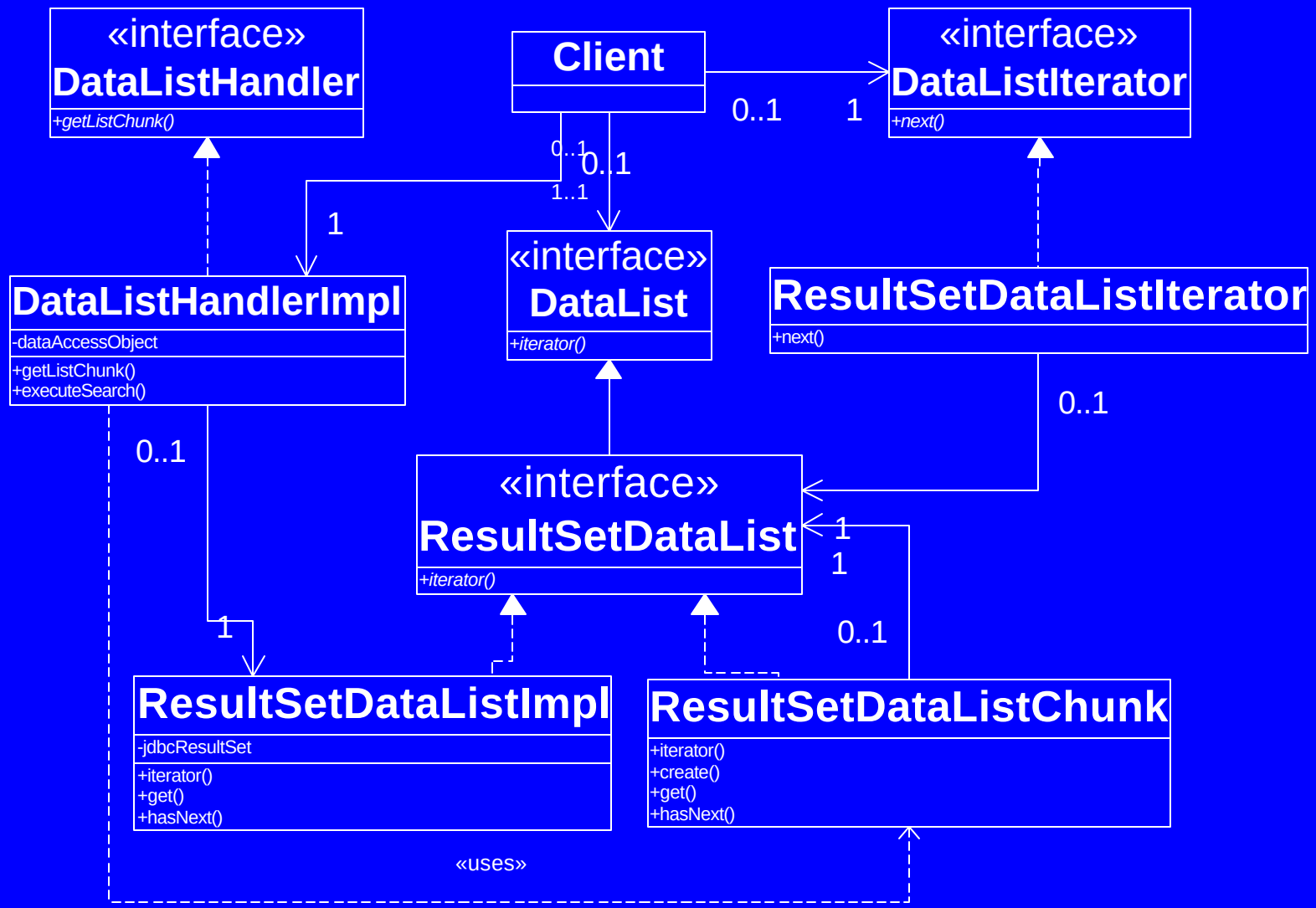
Class: ResultSetDataListChunk implements ResultSetDataList (extends DataList)

- Implements a DataList as a virtual collection that represents a subset of the elements in another ResultSetDataList(DataList)
- Represents a subset of a ResultSetDataList(DataList) that would be retrieved by DataListHandler.getListChunk() to display a page worth of results
- It is a virtual collection that is implemented as a window on another ResultSetDataList
- Because it is simply a window on another collection it is very efficient with low creation overhead

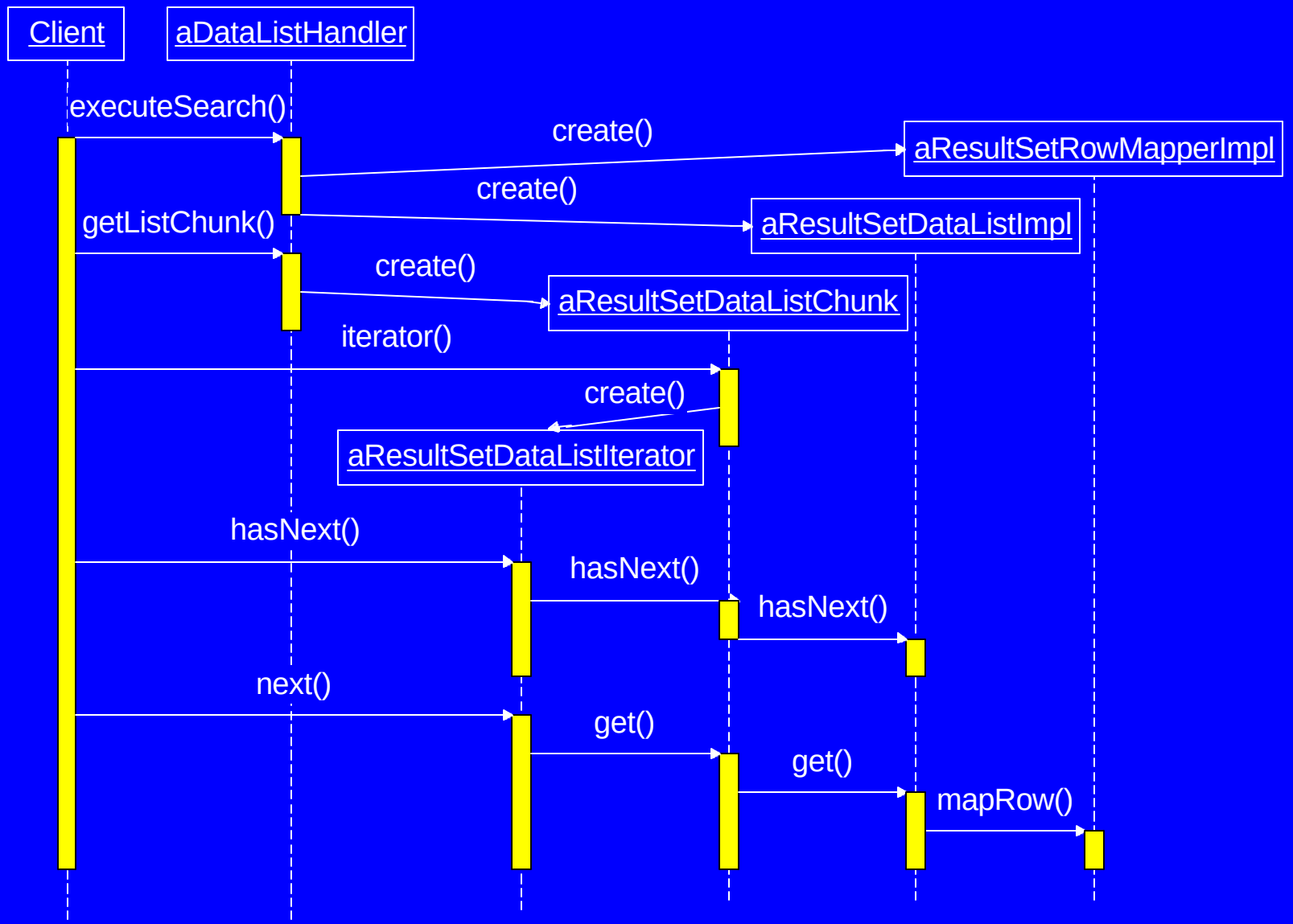
Class: ResultSetIterator implements DataListIterator

- Implementation of DataListIterator that is specialized to iterate over ResultSetDataList's

ResultSetDataList Class Diagram



Sequence Diagram



Clients of ResultSetDataListImpl and ResultSetDataListChunk

- Clients have knowledge only of DataList's
- Clients have no knowledge of ResultSetDataList's
- From client perspective they behave as if they were real collections

Standard ListIterator.next Method

- **Method in the standard Java ListIterator interface is:**
  - public Object next()
- **Returns next Object in collection**
- **Implies that there is a real underlying collection of objects**

DataListIterator.next Method

- **Method Signature:**
  - **public Object next(Object obj)**
- **Copies state of next logical object in collection to passed in object**
- **Returns same object instance to caller**
- **Supports underlying implementations of DataList in which there does not exist a physical collection of objects**
- **A virtual collection of objects is possible**
- **Object is materialized at the time of next method call**
- **Empty object instance is passed in as input to avoid overhead of creating a new Object instance with every next call**
- **Input argument is an object of the same Class as the items in the collection**

DataListIterator.next Method

- Requires a way to map data values of an item instance to the instance variables of the passed in object argument
- Real class of object is not known
- ResultSetIterator uses a ResultSetRowMapper object
- ResultSetRowMapper object maps item data values to instance variables of passed in object

Interface: ResultSetRowMapper

- Provides a way to populate the contents of an Object passed to ResultSetIterator.next method

```
public interface ResultSetRowMapper {

  public Object mapRow(ResultSet rs, Object item)
    throws SQLException;
}
```

- mapRow method accesses a JDBC ResultSet object
- It gets the field values of the current row of the JDBC ResultSet and puts them in the passed in Object

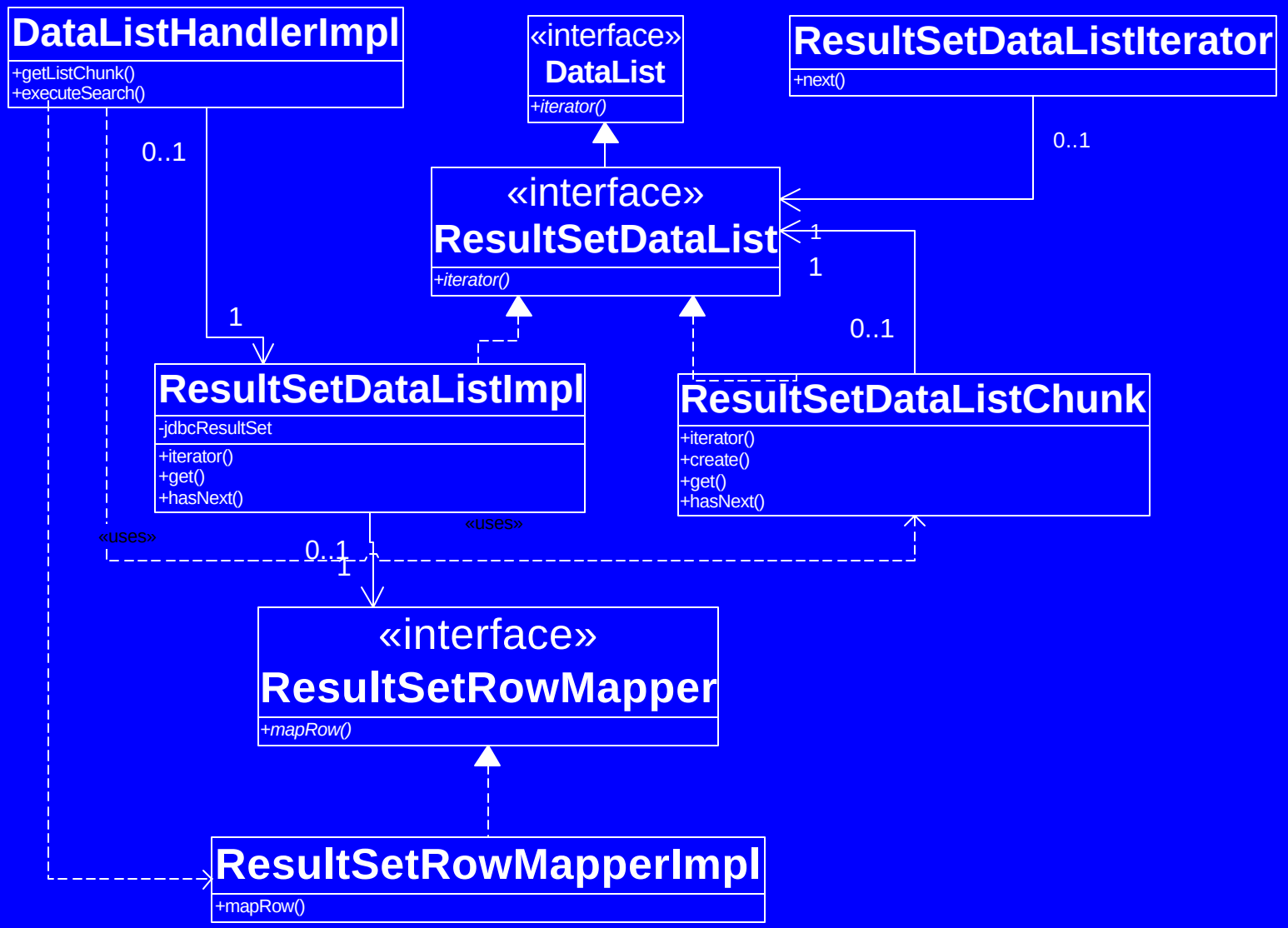
Example: ResultSetRowMapper Class

```
public class ProductRowMapper implements
   ResultSetRowMapper {

   public ProductRowMapper() {
   }

   public Object mapRow(ResultSet rs, Object itemObj)
       throws SQLException {
     ProductDataItem item = (ProductDataItem)itemObj;
     item.id = rs.getInt("ID");
     item.descr = rs.getString("DESCR");
     return item;
   }
}
```

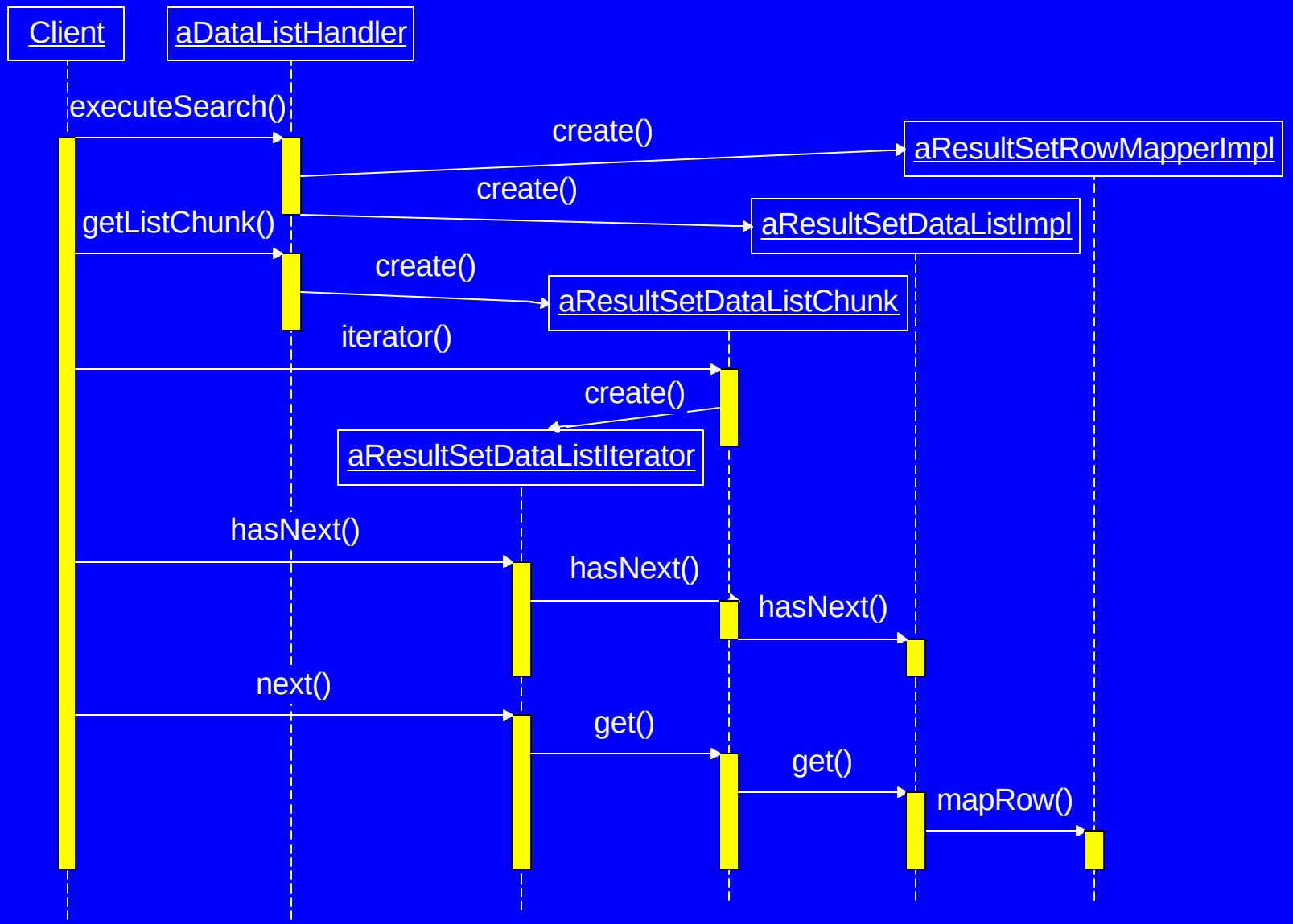
ResultSetRowMapper Interface

- Items of collection are not physically stored in a collection
- Items of collection are actually rows of JDBC Result Set
- ResultSet row field values are retrieved and placed into instance of Object at the time of DataListIterator.next call
- Avoids overhead of creating a new Object instance for each item in collection

ResultSetRowMapper Class Diagram



Sequence Diagram



DataList: Implementation Tier

Servlet Tier

- ResultSetDataListImpl class resides in Servlet Tier
- Client directly accesses ResultSetDataListImpl through DataList interface
- Data Access Object resides in Servlet Tier

EJB Tier

- ResultSetDataListImpl class resides in EJB Tier
- DataAccess Object resides in EJB Tier
- EJB directly access ResultSetDataListImpl through DataList interface

Servlet Tier: Implementation Issues

- JDBC Connection and ResultSet is stored in ResultSetDataListImpl Class object
- ResultSetDataListImpl object must be preserved across Http requests
- Implies that JDBC Connection is maintained across requests
- If a large amount of time lapses between requests, JDBC Connection may remain open for an extended period of time
- Resources wasted with keeping JDBC Connections open across requests

Servlet Tier: Where do we store ResultSetDataListImpl or JDBC Connection across requests

HttpSession object

- JDBC Connection closed when session expires
- Can be costly if session expiration time is long

ServletContext object

- JDBC Connections can be stored in a hash table
- Batch process required to periodically inspect cache of JDBC Connections
- Close connections that have not been accessed in a while
- Cleanup of open JDBC Connection not tied to session expiration.
- More timely cleanup of JDBC Connections

Storing JDBC Connection in ServletContext object

What happens when a user attempts to go to next page after JDBC Connection has expired?

- **Option 1:**
  - Generate error telling user to requery
- **Option 2:**
  - Automatically reestablish connection and reissue query
  - Position cursor to page that was active when user made last request
  - More user friendly option

EJB Tier: How do we preserve ResultSetDataListImpl or JDBC Connection object across requests

- **Stateful Session EJB preserves all state across requests**
- **Options for storing reference to stateful EJB in Servlet tier**
  - HttpSession Object
    - EJB closed when session expires
  - **ServletContext Object**
    - EJB stored in a hash table
    - Batch process inspects hash table periodically to close idle EJB's
    - More timely cleanup of idle EJB's

Minimize Impact of Long Lived Open Connections

- Utilize
  - Shared Server
  - Connection Pooling
  - Session Multiplexing
- Oracle 9i implementation of these features is very efficient
- Overhead of a connection is minimal
- Capable of handling 1000's of open connections

Example: Client Class

```
public class Client1 {

  ProductDataItem item = new ProductDataItem();
  ProductHandler handler; // implements DataListHandler

  public boolean doSearch(String keywords)
      throws ProductHandlerException, DataListException {
    handler = new ProductHandler();
    handler.executeQuery(keywords);
    return handler.elementExists(0);
  }

 ...
```

Methods of Client Class: Continued

```
public DisplayStatus displayPage(int startIndex, int count) throws
    DataListException {

  DataList dl = handler.getListChunk(startIndex, count);
  DataListIterator iterator = dl.iterator();

  int i = startIndex;
  while (iterator.hasNext()) {
    item = (ProductDataItem)iterator.next(item);
    i++;
  }
  boolean moreBefore;
  if (startIndex == 0)
    moreBefore = false;
  else
    moreBefore = handler.elementExists(startIndex-1);
  boolean moreAfter = handler.elementExists(i);
  // Return object which indicates wether more before or more after
  return new DisplayStatus(moreBefore, moreAfter);
}
```

Methods of Client Class: Continued

```
…

/**
 * Closes DataListHandler class to
 * release resources which includes
 * Database Connection
 */
public void cleanup()
    throws DataListException {
  handler.close();
}

}
```

ProductHandler Class

```
public class ProductHandler implements DataListHandler {

  private ProductCatalogDAO productCatalog;
  ResultSetDataList productDataList;

  public ProductHandler() throws … {
    try {
      productCatalog = ProductCatalogDAOFactory.createInstance();
    } catch ... // handle exception
  }

  // Execute query.
  // DAO returns a ResultSetDataList representing search results
  public void executeQuery(String keywords) throws ..{
    try {
      productDataList = productCatalog.executeQuery(keywords);
    } catch ... // handle exception
  }

  ...
```

Methods of ProductHandler Class: Continued

```
// Get subset of elements in result set
public DataList getListChunk(int startIndex, int count)
    throws DataListException {
  return new ResultSetDataListChunk(
      productDataList, startIndex, count);
  }

public boolean elementExists(int index) … {
  try {
    return productDataList.elementExists(index);
  } catch ... // handle exception
}

public void close() throws … {
  productDataList.close();
}
```

```
public class ResultSetDataListImpl implements   ResultSetDataList {

  private ResultSetRowMapper rowMapper;
  private Connection conn;
  private Statement stmt;
  private ResultSet rs;

  public ResultSetDataListImpl(ResultSetRowMapper rowMapper,
    Connection conn, Statement stmt, ResultSet rs) {
     …
     // Set instance variables
  }

  public DataListIterator iterator() throws DataListException {
    try {
      return new ResultSetDataListIterator(this);
    } catch ... // Handle exception
  }

  public void close() throws DataListException {
    //close ResultSet, Statement, and Connection
  }
```

ResultSetDataListImpl Class Methods (Continued)

```
// param index Range is 0 .. num_elements.
// Result set index ranges from 1 ..
public Object get(int index, Object item) throws DataListException, … {
  try {
    if (rs.absolute(index+1)) {
      if (rs.getRow() != index + 1)
        throw new IndexOutOfBoundsException();
      return rowMapper.mapRow(rs, item);
    } else
      throw new IndexOutOfBoundsException();
  } catch ... // Handle exception
}

public boolean hasNext() throws SQLException {
  return !rs.isLast() && (rs.getRow() != 0 || rs.isBeforeFirst());
}

public void beforeFirst() throws SQLException {
  rs.beforeFirst();
}
```

ResultSetDataListImpl Class Methods (Continued)

```
/**
 * @param index Range is 0 .. num_elements.
 * Result set index ranges from 1 ..
 */
public boolean absolute(int index) throws SQLException {
  return rs.absolute(index + 1);
}

public boolean isEmpty() throws DataListException {
  try {
    return !rs.isBeforeFirst() &&
      !rs.isAfterLast() &&
      rs.getRow() == 0;
  } catch ... // Handle exception
}
```

ResultSetDataListImpl Class Methods (Continued)

```
  public boolean elementExists(int index)
     throws  SQLException {

    boolean beforeFirst = rs.isBeforeFirst();
    boolean afterLast = rs.isAfterLast();
    int currIndex = rs.getRow();
    boolean exists = rs.absolute(index + 1);
    if (beforeFirst)
      rs.beforeFirst();
    else if (afterLast)
      rs.afterLast();
    else if (currIndex != 0)
      rs.absolute(currIndex);
    return exists;
  }

}
```