has many useful features (such as table inheritance) that we did not cover here. Additionally, its capabilities differ from database system, to database system so, for example, not all the features that are available with MySQL are also available if you use DB2.

### 2.4 Lightweight Directory Access Protocol (LDAP)

We use directories in the real world all the time: telephone books, lists of network accounts, address books, the domain name service (DNS), and so on. Typically, directories are organized hierarchically—as trees—and their entries are often read and rarely modified.

Implementing directories with relational database systems can be a bit complicated. Even though many database vendors added tools for hierarchical queries to their products, using them is still far from being convenient. (Some vendors, including Oracle, even ship a separate directory service that is based on their relational database product.)

Because of this, a standard for accessing directories was created as part of the X.500 directory specification. It was called Directory Access Protocol (DAP). Unfortunately, it was both complex and complicated, and no one implemented it completely.

As a consequence, an easier standard was defined: the Lightweight Directory Access Protocol (LDAP). This is the most widespread directory service in use today.

I'll give a short introduction to LDAP in the rest of this section. If you're already familiar with LDAP you can safely skip it and go directly to Section 2.4, An Address Book for PragBouquet Customers, on page 55.

Simply put, LDAP is to directories what SQL is to relational databases. It helps you to model real-world entities as directory entries (not as tables) that have different attributes. Attributes have a name, a type, and a multidimensional value; i.e., attributes can have a list of values. Every directory entry (from now on we call them entries for short) has at least one attribute called objectclass that determines which attributes the entry has.

In LDAP you put all object classes and their according attribute type definitions belonging to a particular problem domain into a schema.

---

The core schema, for example, contains the definition of the residential-Person object class:

```objectclass (  
2.5.6.10  
NAME 'residentialPerson'  
DESC 'RFC2256: an residential person'  
SUP person  
STRUCTURAL  
MUST 1  
MAY (  
  businessCategory $ x121Address $ registeredAddress $  
  destinationIndicator $ preferredDeliveryMethod $  
  telexNumber $ teletexTerminalIdentifier $ telephoneNumber $  
  internationallySDNNumber $ facsimileTelephoneNumber $  
  preferredDeliveryMethod $ street $ postOfficeBox $  
  postalCode $ postalAddress $ physicalDeliveryOfficeName $  
  st $ 1  
)  
)```

This looks similar to SQL’s `CREATE TABLE` statement, doesn’t it? The biggest difference is that the type of the attributes (SQL calls them `columns`) are defined separately. The meaning of the different declarations and keywords is as follows:

- In LDAP, every definition begins with an `object identifier (OID)` that uniquely identifies the object class or attribute type worldwide. OIDs are numbers separated by periods and have to be registered at the Internet Assigned Numbers Authority (IANA).\(^{18}\) Private OIDs always start with 1.3.6.1.4.

- Object classes have a name that is defined with the `NAME` keyword. To prevent name clashes, you should add a unique prefix or postfix to your own object class and attribute type names.

- `DESC` lets you give a human-readable description of the object class.

- The `SUP` keyword points to the superclass of an object class. LDAP is object oriented, and an object class can inherit the attributes of another class. Every class has at least one superclass called `top`.

- An LDAP class can be a `STRUCTURAL`, `AUXILIARY`, or `ABSTRACT` class. Abstract classes are classes that are meant only to be base classes (such as `top`). Classes meant to define completely new object hier-

\(^{18}\) [http://www.iana.org/cgi-bin/enterprise.pl](http://www.iana.org/cgi-bin/enterprise.pl)
archies are declared as STRUCTURAL. AUXILIARY classes let you “mixin” attributes into existing structural classes.

- **MUST** expects a dollar-separated list which contains the classes’ mandatory attributes.
- **MAY** expects a dollar-separated list containing the classes’ optional attributes.

Attribute types, such as the telephoneNumber attribute we have used in the residentialPerson object class, are defined as follows:

```plaintext
attributetype (  
  2.5.4.20
  NAME 'telephoneNumber'
  DESC 'RFC2256: Telephone Number'
  EQUALITY telephoneNumberMatch
  SUBSTR telephoneNumberSubstringsMatch
  SYNTAX 1.3.6.1.4.1.1466.115.121.1.50{32}
)
```

Like an object class, the attribute type definition starts with an OID. NAME and DESC have the same meaning as in the object class definition. The remaining keywords have the following meaning:  

- **EQUALITY** specifies which algorithm should be used to test whether two telephoneNumber attributes are equal. This is a little bit more sophisticated than a simple string comparison, because telephone numbers often contain characters only for better readability. For example, “0049 (0) 1234 / 56 78” and “004912345678” are completely different strings, but they represent the same telephone number. The LDAP standard defines a lot of equality algorithms.

- **SUBSTR** lets you define which algorithm should be used to check whether a particular telephoneNumber number attribute contains a particular substring.

- The **SYNTAX** element refers to the OID of the attributes’ syntax. LDAP defines a syntax for many types that are used often such as integers, strings, timestamps, and even JPEG files.

It’s not difficult to build your own object classes and attribute types, but it’s certainly a good idea first to check whether the object class you need has not already be defined. LDAP specifies dozens of base classes for

---

19To learn about attribute types, you have to read RFC 2252: http://www.faqs.org/rfcs/rfc2252.html.
all the elements you typically find in directories: person, residentialPerson, organizationalPerson, and so on. Often it’s sufficient to derive a new class from an existing one, adding just a few attributes. For example, if you need to store address data containing the geographical position of the address, you can derive a new geoPerson class from residentialPerson, adding longitude and latitude attributes.

That’s all not too different from what you do with relational databases (except for the inheritance features), and you could use LDAP to store nonhierarchical data. But usually LDAP repositories represent hierarchical trees of entries belonging to one or more object classes.

Each entry has a unique name, the distinguished name (DN). The DN consists of several relative distinguished names (RDN). An RDN is a list of attribute name/value pairs that are separated by a comma or a semicolon. For example, telephoneNumber=004912345678 could be an RDN with the attribute name telephoneNumber and the value 004912345678. A more precise RDN could be

cn=Maik Schmidt,telephoneNumber=004912345678

This additionally specifies the cn ("common name") attribute of a person object.

As we all know, a picture is worth approximately $2^{10}$ words, so let’s have a look at Figure 2.3, on page 59. The root entry of the directory in this figure has a DN consisting of two RDNs: dc=pragbouquet,dc=com. It automatically becomes an RDN for all entries in the tree. The deeper you go down the hierarchy, the longer the DNs and RDNs get. For example, the distinguished names of all entries on the left side contain the relative distinguished name uid=4711,dc=pragbouquet,dc=com. Simply put, DNs specify leaves, and RDNs specify subtrees.

LDAP allows you to read, modify, and delete subtrees and single nodes of your directories. In relational databases you specify particular rows with a WHERE clause in your SQL statements. In LDAP you use RDNs and DNs to do so.

We mentioned before that directory entries are often read and rarely updated. Hence, the LDAP standard defined a technology that makes an initial import of directory entries easy: the LDAP Data Interchange Format (LDIF). It’s a simple textual file format for describing directory entries.

---

20 dc stands for domain component. dc is a mandatory attribute for entries belonging to the organization object class.
entries. Here’s an LDIF representation of the root entry and one of its
descendants of our sample directory:

# First (root) entry: the PragBouquet organization.
dn: dc=pragbouquet,dc=com
objectclass: dcObject
objectclass: organization
o: PragBouquet
dc: pragbouquet

# Second entry: an address book for customer 4711.
dn:uid=4711,dc=pragbouquet,dc=com
objectclass: top
objectclass: person
objectclass: uidObject
uid: 4711
cn: John Jackson
sn: Jackson

LDIF is line oriented. Comment lines start with a # character. All the
other lines represent an attribute and its corresponding value, sepa-
rated by a colon. If an attribute has more than one value, it may
appear several times. Every LDAP server comes with a bunch of utili-
ties for modifying an existing repository and for importing .ldif files.

Although a lot of directory services work more or less invisibly, touched
only by your system administrators, chances are good that you'll have
to integrate with one someday, because LDAP is gaining popularity
among application developers, too. In the following sections we'll show
how to manipulate a directory service based on OpenLDAP with Ruby.

An Address Book for PragBouquet Customers

The marketing department made yet another astonishing observation:
there are people who celebrate their birthdays every year! Wouldn't it
be great if PragBouquet customers could easily send them a bouquet
on those birthdays? And wouldn't it be nice if PragBouquet customers
could be spared the extra work of entering the same address data for
the recipients, over and over again?

So, marketing came up with an ingenious idea. All PragBouquet cus-
tomers should have their own address book where they can store the
addresses of the people they've ever sent a bunch of flowers.

http://www.faqs.org/rfcs/rfc2849.html
The web shop team said that it’s not a big deal to create a user interface for the address book, but they asked you to create the corresponding backend services. Fortunately, they want to give Ruby on Rails\(^\text{22}\) a try, so you can use Ruby for implementing the address book logic.

When thinking about things like address books, LDAP immediately comes to mind, so you decide to implement the address book as a directory service using the OpenLDAP\(^\text{23}\) system. It has everything you need, it’s available for free, it works on top of several database systems, and it ships with several utilities for reading and manipulating data.

For the development phase we install an OpenLDAP server on our local machine and configure it using this configuration file:

```
include /sw/etc/openldap/schema/core.schema

- database bdb
- suffix "dc=pragbouquet,dc=com"
5 rootdn "cn=root,dc=pragbouquet,dc=com"
- rootpw secret
- directory /sw/var/openldap-data
- index objectclass eq
```

That is really all we need to get our address book application up and running. We have to include the core schema, because we’ll need some of its definitions (person, residentialPerson, and uidObject). In addition, we have to define the database we want to use (the LDAP standard does not define how the directory is to be stored). It’s a Berkeley DB (bdb)\(^\text{24}\) with all data files stored in directory /sw/var/openldap-data. The distinguished name of our root node (needed for administrative purposes only) is cn=root,dc=pragbouquet,dc=com. We have to authenticate ourselves using the nearly unbreakable plain-text password secret whenever we want to write to the database.

LDAP allows you to create a sophisticated directory layout for address books comprising lots of organizational units or even define your own object classes, but we will use a more modern and simpler approach. We will organize our directory in a flat way using domain components and uid attributes.\(^\text{25}\)

---

\(^{22}\) [http://www.rubyonrails.com](http://www.rubyonrails.com)

\(^{23}\) [http://www.openldap.org](http://www.openldap.org)

\(^{24}\) [http://sleepycat.com](http://sleepycat.com)

\(^{25}\) [http://www.faqs.org/rfcs/rfc2377.html](http://www.faqs.org/rfcs/rfc2377.html)
Before diving into Ruby code, let's take a closer look at the directory structure and then initialize our repository with some sample data stored in init.ldif:

```ruby
# Create the PragBouquet organization.
- dn: dc=pragbouquet,dc=com
- objectclass: dcObject
- objectclass: organization
  o: PragBouquet
  dc: pragbouquet

# Create an address book for customer 4711.
- dn: uid=4711,dc=pragbouquet,dc=com
  objectclass: top
  objectclass: person
  objectclass: uidObject
  uid: 4711
  cn: John Jackson
  sn: Jackson

# Create the first address book entry for customer 4711.
- dn: cn=Marge Jackson,uid=4711,dc=pragbouquet,dc=com
  objectclass: top
  objectclass: residentialPerson
  cn: Marge Jackson
  sn: Jackson
  l: Springfield
  st: IL
  street: Evergreen Terrace 42
  postalCode: 62701
  description: Don't forget our wedding anniversary!

# Create the second address book entry for customer 4711.
- dn: cn=P.H. Beans,uid=4711,dc=pragbouquet,dc=com
  objectclass: top
  objectclass: residentialPerson
  cn: P.H. Beans
  sn: Beans
  l: Springfield
  st: MO
  street: Nuclear Powerplant Road 1
  postalCode: 65801
  description: My boss.

# Create an address book for customer 0815.
- dn: uid=0815,dc=pragbouquet,dc=com
  objectclass: top
  objectclass: person
  objectclass: uidObject
  uid: 0815
```
The previous LDIF file should be nearly self-explanatory (comment lines start with a # character). Every entry has a distinguished name (DN). All its other attributes are listed as “key: value” pairs. All attributes are potentially multidimensional, so they may appear several times.

Note that we use the attribute uid to structure our address books. Every web shop user is identified by a particular identifier (it might be a customer ID, an e-mail address, or something similar). Whenever a customer creates a completely new address book (not an address book entry), a new directory entry for her user ID will be added. The directory belonging to our init.ldif file looks like Figure 2.3, on the next page (we have left out most attributes for brevity).

Let’s start our server and load the initial data using the ldapadd command:

```
mschmidt:~/ldap> sudo slapd
Password:
mschmidt:~/ldap> ldapadd -c -x -D "cn=root,dc=pragbouquet,dc=com" \
> -W -f init.ldif
Enter LDAP Password:
adding new entry "dc=pragbouquet,dc=com"

adding new entry "uid=4711,dc=pragbouquet,dc=com"

adding new entry "cn=Marge Jackson,uid=4711,dc=pragbouquet,dc=com"

adding new entry "cn=P.H. Beans,uid=4711,dc=pragbouquet,dc=com"

adding new entry "uid=0815,dc=pragbouquet,dc=com"

adding new entry "cn=Jane Doe,uid=0815,dc=pragbouquet,dc=com"
```
Our .ldif file didn’t contain any errors, and six new entries have been created.

OpenLDAP’s ldapsearch command allows us to query the repository. It prints its results in LDIF. To become a bit more familiar with our directory, let’s print the address book of the user identified by uid 4711:

```bash
mschmidt:~/ldap> ldapsearch -x -s one \
> -b 'uid=4711,dc=pragbouquet,dc=com' \
> ' (objectclass=*)'
# extended LDIF
#
# LDAPv3
# base <uid=4711,dc=pragbouquet,dc=com> with scope one
# filter: (objectclass=*)
# requesting: ALL
#
#
# Marge Jackson, 4711, pragbouquet.com
dn: cn=Marge Jackson,uid=4711,dc=pragbouquet,dc=com
objectClass: top
```

Figure 2.3: Address Book Layout
objectClass: residentialPerson
cn: Marge Jackson
sn: Jackson
l: Springfield
st: IL
street: Evergreen Terrace 42
postalCode: 62701
description: Don't forget our wedding anniversary!

# P.H. Beans, 4711, pragbouquet.com
dn: cn=P.H. Beans,uid=4711,dc=pragbouquet,dc=com
objectClass: top
objectClass: residentialPerson
cn: P.H. Beans
sn: Beans
l: Springfield
st: MO
street: Nuclear Powerplant Road 1
postalCode: 65801
description: My boss.

# search result
search: 2
result: 0 Success

# numResponses: 3
# numEntries: 2

Obviously, everything is up and running. Our query returned the two address book entries that belong to the customer identified by user ID 4711. But what are those options we passed to the command?

- `-x` uses the simple authentication mechanism. In our case the communication is unencrypted, and no password is needed.

- `-s` one searches the directory “one level beyond base,” so it returns all entries below our search base, but not the base itself. `-s base` would have returned the base object only, and `-s sub` would have returned the base object and all its descendants.

- `-b 'uid=4711,dc=pragbouquet,dc=com'` sets the search base to the distinguished name `uid=4711,dc=pragbouquet,dc=com`, so that all entries of the subtree belonging to this DN will be returned.

- `(objectclass=*)` specifies a filter for the entries to be returned. The `(objectclass=*)` filter is comparable to SQL’s `SELECT *` statement and selects all entries no matter what attributes they have. If we were interested in entries from Illinois only, we could have set the filter to `(st=IL)`.
In the following sections we’ll see how to manipulate our repository with Ruby.

**Ruby/LDAP**

The Ruby/LDAP\(^{26}\) library was initially created by Takaaki Tateishi and is currently maintained by Ian Macdonald. It supports all LDAP clients that comply with the LDAP Application Program Interface.\(^{27}\) You can use Ruby/LDAP to interface with OpenLDAP, Netscape, and ActiveDirectory, among others.

As a first exercise we’ll try to read John Jackson’s address book. It should not be too surprising that accessing a directory service looks similar to accessing a relational database system:

```
require 'pp'
require 'ldap'
include LDAP

begin
  connection = Conn.new('127.0.0.1', LDAP_PORT)
  connection.set_option(LDAP_OPT_PROTOCOL_VERSION, 3)
  connection.bind do
    base_dn = 'uid=4711,dc=pragbouquet,dc=com'
    scope = LDAP_SCOPE_ONELEVEL
    filter = '(objectClass=*)'
    connection.search(base_dn, scope, filter) do |entry|
      pp entry.to_hash
    end
  end
rescue Exception => ex
  puts ex
end
```

This prints the following:

```
{
  "cn" => ["Marge Jackson"],
  "st" => ["IL"],
  "l" => ["Springfield"],
  "sn" => ["Jackson"],
  "description" => ["Don’t forget our wedding anniversary!"]
}
```

\(^{26}\)[http://ruby-ldap.sourceforge.net]

\(^{27}\)[http://www.faqs.org/rfcs/rfc1823.html]
"st"=>["MO"],
"l"=>["Springfield"],
"sn"=>["Beans"],
"description"=>["My boss."],
"postalCode"=>["65801"],
"street"=>["Nuclear Powerplant Road 1"],
"objectClass"=>["top", "residentialPerson"],
"dn"=>["cn=P.H. Beans,uid=4711,dc=pragbouquet,dc=com"]}

First, we create a new connection to the LDAP service by calling the method `LDAP::Conn.new(host='localhost', port=LDAP_PORT)`. We then set the `LDAP_OPT_PROTOCOL_VERSION` option, because we've set up an LDAPv3 service (it's OpenLDAP's default).

In line 8 we bind our connection object to the server. The real work is performed in the code block we pass to the `bind(dn=nil, password=nil, method=LDAP_AUTH_SIMPLE)` method. The heart of our “program logic” is the `search()` method. It expects the following parameters:

1. `base_dn` contains the base DN of the subtree to search in.
2. `scope` defines the search scope: one of: `LDAP_SCOPE_ONELEVEL`, `LDAP_SCOPE_SUBTREE`, or `LDAP_SCOPE_BASE`.

   In our example we have used `LDAP_SCOPE_ONELEVEL`, which means “one level beyond base.” We are not interested in the base object (the address book owner) itself.

   If we had set the scope to `LDAP_SCOPE_SUBTREE` the program would have printed the entry for the address book owner, too:

   ```
   {
   "cn"=>["John Jackson"],
   "sn"=>["Jackson"],
   "uid"=>["4711"],
   "description"=>["Address book of John Jackson."],
   "objectClass"=>["top", "person", "uidObject"],
   "dn"=>["uid=4711,dc=pragbouquet,dc=com"]
   ...
   ```

   `LDAP_SCOPE_BASE` returns only the base object (the address book owner in our case).

3. `filter` contains the LDAP search filter to be used.
4. The `attributes` array contains the name of the attributes which will be returned. If it is empty or `nil` (the default), all attributes are returned.
5. The `attributes_only` flag indicates whether only the names of the attributes should be returned (true). When it is set to false (the default), it returns both names and values.
6. `seconds` specifies the seconds portion of the search timeout. It defaults to 0. If either this parameter or the `useconds` parameter is greater than 0, the timeout mechanism will be activated.

7. `useconds` specifies the microseconds portion of the search timeout. It defaults to 0. If this parameter or the `seconds` parameter is greater than 0, the timeout mechanism will be activated. To set a timeout of 2.5 seconds, set `seconds` to 2 and `useconds` to 500.

8. `sort_attribute` specifies the attribute by which to sort the search result entries. If no sort attribute is specified (the default), the order of the result entries is unpredictable.

9. `sort_proc` may contain a code block that is used for sorting the entries returned by the server. It defaults to `nil`, so the order of the result entries is unpredictable.

`search()` is an iterator. It expects a code block that gets passed the current entry as an `LDAP::Entry` object. In line 13 we turn these objects into hashes and print them, nicely formatted.

Reading LDAP entries seems to be fairly easy. Let’s try to create new ones now. First let’s add an empty address book for Jane Doe (she is already a member of Max Mustermann’s address book, but that doesn’t matter, because for us they are two different customers):
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