to a computer database which continues to expand at the rate of approximately 6000 records per year. To make this data generally available, it was decided to publish the whole *Index Kewensis* as a CD-ROM in 1993. This contains almost 968,000 records.

Illustrations of vascular plants can be located through *Index Londinensis*, which contains information up to 1935. More recent information can be found in the 2-volume work *Flowering Plant Index of Illustrations and Information* compiled by R. T. Isaacson (1979).

A listing of all generic names can be found in *Index Nominum Genericorum* (ING) a 3-volume work published in 1979 under the series *Regnum Vegetabile*. The first supplement appeared in 1986. It has now been put on the database and can be directly accessed through the Internet.

Index Holmiensis (earlier *Index Holmensis*) is an alphabetic listing of distribution maps found in taxonomic literature of vascular plants. It commenced publication in 1969.

Gray Herbarium Card Index is information on cards, which has now been set up on a database. Usually on the same pattern as *Index Kewensis*, the Index has been published in 10 volumes between 1893 and 1967. A 2-volume *supplement* was published by G. K. Hall in 1978. The *Gray Herbarium Index* Database currently includes 350,000 records of New World vascular plant taxa at the level of species and below. The Index includes from its 1886 starting point, the names of plant genera, species and all taxa of infraspecific rank. The Gray Index has in common with *Index Kewensis* its involvement with taxon names, although they differ in biological and geographical coverage. The *Gray Index* covers vascular plants of the Americas; *Index Kewensis* includes seed plants worldwide. Only the *Gray Index* has nomenclatural synonyms cross-referenced to basionyms. The information is now accessible over the Internet via keyword searches from the E-mail Data Server and through the Biodiversity and Biological Collections Gopher. Indices covering other groups of plants have also been published: *Index Filicum* for Pteridophytes, and *Index Muscorum* for Bryophytes.

The *Hu Card Index* is a file of 158,844 cards for Chinese plant names, now housed in the Harvard University Herbaria building where it is available for use in person. The Index was produced by Dr. Hu Shiu-ying (Arnold Arboretum of Harvard University) and his staff. The Hu Card Index was prepared in the early 1950s when the Arnold Arboretum undertook a project to prepare a flora of China.

Royal Botanic Gardens Kew, The Harward University Herbaria, and the Australian National Herbarium, under the collaborative project, have developed *International Plant Names Index* (IPNI), a single web database which combines citation data for seed plants from *Index Kewensis*, the *Gray Herbarium Card Index*, and the *Australian Plant Names Index* (APNI). It provides information on names and associated basic bibliographical details of all seed plants. Its goal is to eliminate the need for repeated reference to primary sources for basic bibliographic information about plant names. The data are freely available and are gradually being standardized and checked. IPNI is intended to be a dynamic resource, depending on direct contributions by all members of the botanical community.

Numerous valuable **Dictionaries** have been published but by far the most useful is *Dictionary of Flowering Plants and Ferns* published by J. C. Willis. The 8th edition revised by Airy Shaw appeared in 1973. The book contains valuable information concerning genera and families providing name of the author, distribution, family and the number of species in the genus.

Taxonomic Keys

Taxonomic keys are ***aids for rapid identification of unknown plants***. They constitute important component of Floras, manuals, monographs and other forms of literature meant for the identifying plants. In addition, identification methods in recent years have incorporated the usage of keys

based on cards, tables and computer programs. The latter are primarily designed for identification by non-professionals. These keys are fundamentally based on characters, which are stable and reliable. The keys are helpful in a faster preliminary identification, which can be backed up by confirmation through comparison with the detailed description of the taxon provisionally identified with. Before identification is attempted, however, it is necessary that the unknown plant is carefully studied, described and a list of its character states prepared. Based on the arrangement of characters and their utilization, two types of identification keys are differentiated:

1. Single-access or sequential keys; and
2. Multi-access or multientry keys (polyclaves).

Single Access or Sequential Keys

Single-access keys are usual components of Floras, manuals, monographs and other books meant for identification. The keys are based on **diagnostic** (important and conspicuous) characters (**key characters**) and as such the keys are known as **diagnostic keys**. Most of the keys in use are based on pairs of contrasting choices and as such are **dichotomous keys**. They were first introduced by J. P. Lamarck in his *Flore Francaise* in 1778. The construction of a dichotomous key starts with the preparation of a list of reliable characters for the taxon for which the key is to be constructed. For each character the two contrasting choices are determined (e.g., habit woody or herbaceous). Each choice constitutes a **lead** and the two contrasting choices form a **couplet**. For characters having more than two available choices the character can be split to make it dichotomous. Thus if flowers in a taxon could be red, yellow or white the first couplet would constitute flowers red vs. non-red and the second couplet flowers yellow vs. white. We shall illustrate the construction of keys taking an example from family Ranunculaceae. The diagnostic characters of some representative genera are listed below:

1. *Ranunculus*: Plants herbaceous, fruit achene, distinct calyx and corolla, spur absent, petal with nectary at base.
2. *Adonis*: Plants herbaceous, fruit achene, calyx and corolla differentiated, spur absent, petals without nectary.
3. *Anemone*: Plants herbaceous, fruit achene, calyx not differentiated, perianth petaloid, spur absent.
4. Clematis: Plants woody, fruit achene, calyx not differentiated, perianth petaloid, spur absent.
5. *Caltha*: Plants herbaceous, fruit follicle, calyx not differentiated, perianth petaloid, spur absent.
6. *Delphinium*: Plants herbaceous, fruit follicle, calyx not differentiated, perianth petaloid, spur one in number.
7. *Aquilegia*: Plants herbaceous, fruit follicle, calyx petaloid, not differentiated from corolla, spurs five in number.

Based upon the above information the following couplets and leads can be identified:

1. Plants woody
   Plants herbaceous
2. Fruit achene
   Fruit follicle
3. Calyx and corolla differentiated
   Calyx and corolla not differentiated
4. Spur present
   Spur absent
5. Number of spurs 1
   Number of spurs 5
6. Petal with nectary at base
   Petal without nectary at base

It must be noted that three choices are available for spur (absent, one, five). It has been broken into two couplets to maintain the dichotomy. Based on the arrangement of couplets and their leads, three main types of dichotomous keys are in use: **Yoked** or **Indented key, Bracketed** or **parallel key,** and **Serial** or **numbered key**.

1. **Yoked** or **Indented key**: This is one of the most commonly used keys in Floras and

1 Stem woody at base; achenes 3.5-5 mm **8. pustulatus**
1 Stem not woody; achenes 2-3.75 mm
2 Annual or biennial
3 Achenes smooth at least between the ribs; strongly compressed and ± winged **1. asper**
3 Achenes rugose or tuberculate between the ribs, neither strongly compressed nor winged
4 Leaf-lobes strongly constricted at base, or narrowly linear; terminal lobe usually about as large as lateral lobes; ligules longer than corolla-tube; achenes abruptly contracted at base **2. tenerrimus**
4 Leaf-lobes (if present) not constricted at base; terminal lobe usually much larger than lateral lobes; ligules about as long as corolla-tube; achenes gradually narrowed at base **3. oleraceous**
2 Perennial

Figure 5.15 Portion of a polythetic key of the yoked type used in *Flora Europaea* for genus *Sonchus* (vol. 4, p. 327).

manuals especially when the keys are smaller in size. In this type of key, the statements (leads) and the taxa identified from them are arranged in visual groups or yokes and additionally the subordinate couplets are indented below the primary one at a fixed distance from the margin, the distance increasing with each subordinate couplet. We shall select the fruit type as the first couplet, as it divides the group into two almost equal halves and the taxa excluded would be almost equal whether the fruit in the unknown plant is an achene or a follicle. The yoked or indented key for the taxa under consideration is shown below:

1. Fruit achene.
2. Calyx differentiated from corolla.
3. Petal with basal nectary 1. *Ranunculus*
3. Petal without basal nectary..2. *Adonis*
2. Calyx not differentiated from corolla.
4. Plants woody.....4. *Clematis*
4. Plants herbaceous.....3. *Anemone*
1. Fruit follicle.
5. Spur present.
6. Number of spurs 1.....6. *Delphinium*
6. Number of spurs 5.....7. *Aquilegia*
5. Spur absent.....5. *Caltha*

It is important to note that all genera with achene fruit appear together and form visual groups; leads of subordinate couplets are at increasing distance from the margin and the leads of initial couplets are far separated, whereas those of subsequent subordinate couplets are closer. Such an arrangement is very useful in shorter keys, especially those appearing on a single page, but if the key is very long running into several pages, an Indented key exhibits important drawbacks. Firstly, it becomes difficult to locate the alternate leads of initial couplets, as they may appear on any page. Secondly, with the number of subordinate couplets increasing substantially, the key becomes more and more sloping, thus reducing the space available for writing leads. This may result in wastage of a substantial page space. The problem is clearly visible in *Flora Europaea* where attempts to reduce the indentation distance in longer keys has further complicated the usage of keys. These two disadvantages are taken care of in the Parallel or Bracketed key.

2. **Bracketed** or **Parallel key**: This type of key has been used in larger floras such as *Flora of USSR*, *Plants of Central Asia*, and *Flora of British Isles*. The two leads of a couplet are always together and the distance from the margin is always the same. Several variations of this are used wherein the second lead of the couplet is not numbered, as in *Flora of British Isles* or else the second lead is prefixed with a + sign as in *Plants of Central Asia*. The arrangement of couplets in this type of key is useful for longer keys as the location of alternate keys is no problem (two are always together) and there is no wastage of page space. There is, however, one associated drawback; the statements are no longer in visual groups. The reference to primary lead is often difficult, but this problem is usually solved by indicating the number of primary lead within parenthesis as done in several Russian Floras such as *Flora Siberia* and *Plants of Central Asia*. A typical bracketed key is illustrated below:

1. Fruit achene.....1
1. Fruit follicle.....5
2. Calyx differentiated from corolla.....3
2. Calyx not differentiated from corolla....4
3. Petal with basal nectary..1. *Ranunculus*
3. Petal without basal nectary..2. *Adonis*
4. Plants woody.....4. *Clematis*
4. Plants herbaceous.....3. *Anemone*
5. Spur present.....6
5. Spur absent.....5. *Caltha*
6. Number of spurs 1.....6. *Delphinium*
6. Number of spurs 5.....7. *Aquilegia*

Retention of positive features of the Parallel key and visual groups of the Yoked key is achieved in the Serial key.

3. **Serial** or **numbered key**: Such a key has been used for the identification of animals and also adopted in some botanical works. This key retains the arrangement of Yoked key, but with no indentation so that distance from the margin remains the same. The location of alternate leads is made possible by serial numbering of couplets (or leads when separated) and indicating the serial number of the alternate lead within parentheses. A serial key for the taxa in question would appear as under:

1. (6) Fruit achene.
2. (4) Calyx differentiated from corolla.
3. Petal with basal nectary..1. *Ranunculus*
3. Petal without basal nectary...2. *Adonis*
4. (2) Calyx not differentiated from corolla.
5. Plants woody.....4. *Clematis*
5. Plants herbaceous..... 3. *Anemone*
6. (1) Fruit follicle.
7. (9) Spur present.
8. Number of spurs 1.....6. *Delphinium*
8. Number of spurs 5.....7. *Aquilegia*
9. (7) Spur absent.....5. *Caltha*

Such a key retains the visual groups of statements and taxa, alternate leads, even though separated, are easily located and the there is no wastage of page space.

An inherent drawback of dichotomous keys is that the user has a single fixed choice of the sequence of characters decided by the person who constructs the key. In the said example if information about the fruit is not available, it is not possible to go beyond the first couplet.

Guidelines for dichotomous keys

Certain basic considerations are important for the construction of dichotomous keys. These include:

1. The keys should be strictly dichotomous, consisting of couplets with only two possible choices.
2. The two leads of a couplet should be mutually exclusive, so that the acceptance of one should automatically lead to the rejection of another.
3. The statements of the leads should not be overlapping. Thus, the two leads 'leaves 5-25 cm long' and 'leaves 20-40 cm long' would find it difficult to place taxa with leaves that are between 20 and 25 cm in length.
4. The two leads of a couplet should start with the same initial word. In our example, both leads of the first couplet start with 'Fruit'.

5. The leads of two successive couplets should not start with the same initial word. In our example the word 'spur' appears in two successive couplets and as such in the second one the language has been changed to start with 'Number'. If such a change were not possible it would be convenient to prefix the second couplet with 'The'. Thus, the other alternative for the second couplet would have the two leads worded as 'The spur 1' and 'The spurs 5'.
6. For identification of trees, two keys should be constructed based on vegetative and reproductive characters separately. As trees commonly have leaves throughout the major part of the year, and flowers appear briefly when in many trees leaves are not yet developed, such separate keys are essential for identification round the year.
7. Avoid usage of vague statements. Statements such as 'Flowers large' vs. 'Flowers small' may often be confusing during actual identification.
8. An initial couplet should be selected in such a way that it divides the group into more or less equal halves, and the character is easily available for study. Such a selection would make the process of exclusion faster, whichever lead is selected.
9. For dioecious plants, it is important to have two keys based on male and female flowers separately.
10. The leads should be prefixed by numbers or letters. This makes location of leads easier. If left blank, the location of leads is very difficult, especially in longer keys.

The keys described above have a single character included in a couplet, with two contrasting statements about the character in the two leads. Such keys are known as **monothetic sequential keys**. The commonest forms of keys used in floras, however, have at least some couplets (Fig 5.15) with several statements about the different characters in each lead. These keys are known as **polythetic sequential keys**. Such polythetic keys, also known as **synoptic keys** are especially useful for constructing keys for higher categories. Such keys have three basic advantages over the monothetic keys:

1. One or more characters may be unobservable due to damage or non-occurrence of requisite stage in the specimen. In such cases, a monothetic key becomes useless.
2. User can make a mistake in deciding about a single character. This error gets minimized if more than one character is used.
3. The single character used in the couplet may be exceptional. Such likelihood is not possible when more than one character is used.

Multi-Access Keys (Polyclaves)

Such multientry order-free keys are user-oriented. Many choices of the sequence of characters are available. Eventually, it is the user who decides the sequence in which to use the characters, and even if the information about a few characters is not available, the user can go ahead with identification. Interestingly, identification may often be achieved without having to use all the characters available to the user. Such identification methods often make use of cards. Two basic types of cards are in use:

Body-punched cards

These cards are also named **window cards** or **peek-a-boo cards**, and make use of cards with appropriate holes in the body of the card (Figure 5.16). The process involves using one card for one attribute (character-state). In our example we shall need 11 cards (we have chosen only diagnostic characters above, whereas our list in polyclaves could include more characters, and thus more cards to make it more flexible).

It should be noted that we selected 12 leads and 6 couplets, with 4 leads for spur. Now we shall need only three actual attributes: 'spur absent', 'spur 1' and 'spurs 5'. Numbers are printed on the cards corresponding to the taxa for which the identification key is meant. In our example, we use only 7 of these numbers corresponding to our