parts. Roots are useful, however, in determining whether a plant is an annual or a perennial, and variation in the root system is sometimes taxonomically significant. A few important terms relating to roots are listed below.

**adventitious** developing from a plant part other than another root

**stem system** root system being of a well branched hydrate storage tissue linking other plants and on them (as in para-

ta, the major root, usually enlarged and growing downward

**STEMS**
Stems—the axes of plants—consist of nodes, where leaves and axillary buds are produced, separated by internodes (Figure 4.2). They are frequently useful in identification and provide numerous systematically important characters.

Stems are usually elongated and function in exposing leaves to sunlight. Some, however, may be photosynthetic (as in asparagus, Asparagusaceae, and many cacti, Cactaceae), store water or carbohydrates (many cacti and other succulents), climb (as in hooked or twining stems of vines and lianas), or protect the plant (as in plants with thorns). In addition to terms already mentioned, some important stem-related vocabulary is listed below.

**acaulescent** having an inconspicuous stem

**bulb** a short, erect, underground stem surrounded by thick, fleshy leaves (or leaf bases)

**caulescent** having a distinct stem

**corm** a short, erect, underground, more or less fleshy stem covered with thin, dry leaves (or leaf bases)

**herbaceous** not woody; dying at the end of the growing season

**internode** the part of the stem between two adjacent nodes

**lenticels** wartlike protuberances on the stem surface involved in gas exchange

**long shoot** a stem with long internodes; this term is applied only in plants in which internode length is clearly bimodal and both long and short shoots are present

**node** area of the stem where the leaf and bud are borne

**pith** soft tissue in center of stem, usually consisting of more or less isodiametric cells

**rhizome** a horizontal stem, often underground or lying along the surface of the ground, bearing scalelike leaves; often called a stolon (or runner) if above ground and having an elongated internode

**scape** an erect, leafless stem bearing an inflorescence or flower at its apex; usually composed of a single elongated internode

**scar** the remains of a point of attachment, as in leaf scar, stipule scar, bud-scale scar

**short shoot** a stem with short internodes; see long shoot

**thorn** a reduced, sharp-pointed stem [In contrast, a reduced, sharp-pointed leaf or stipule, or sharp-pointed marginal tooth is called a spine, and a sharp-pointed hair (involving epidermal tissue) or emergence (involving both epidermal and subepidermal tissues) is called a prickle.]

**tuber** a swollen, fleshy portion of a rhizome involved in water or carbohydrate storage

**twining** spiraling around a support in order to climb

**woody** hard in texture, containing secondary xylem, and persisting for more than one growing season

**BUDS**
Buds are short embryonic stems. They may be protected by bud scales (modified leaves), stipules, a dense covering of hairs, or a sticky secretion. In angiosperms they are found at the nodes, in the leaf axil (the angle formed by the stem and the petiole of the leaf; see Figure 4.2) and may also terminate the stem. They are especially useful for identifying twigs in winter condition. Some common terms pertaining to buds are listed below.

**accessory bud** an extra bud (or buds) produced on either side of or above the axillary bud

**axillary bud** a bud located in the leaf axil

**flower bud** a bud containing embryonic flowers

**leaf bud** a bud containing embryonic leaves

**mixed bud** a bud containing both embryonic flowers and leaves

**naked** not covered by bud scales or stipules

**pseudoterminal bud** an axillary bud that has taken over the function of a terminal bud (in sympodial shoots)

**superposed bud** bud(s) located above the axillary bud

**terminal bud** a bud at the apex of a stem (in monopodial shoots)
LEAVES
Leaves are the major photosynthetic parts of most plants. They are borne at the nodes of a stem, usually below a bud (Figures 4.2 and 4.3). In contrast to stems, leaves usually do not continue to grow year after year. They are usually flat, and have one surface facing toward the stem axis (adaxial or upper surface) and another surface facing away from the stem axis (abaxial or lower surface). Most leaves are bifacial, having a definite adaxial and abaxial surface, but sometimes they are unifacial and lack such differentiation. Leaves are homologous structures among the angiosperms, but not among vascular plants as a whole (see Chapter 7). In addition to their obvious function in photosynthesis, leaves may be modified for protection (forming sharp-pointed structures called spines), water storage (as in many succulents), climbing (as in vines or lianas with tendrils leaves), capturing insects (as in carnivorous plants), or providing homes for ants or mites (forming domatia, as described later).

The major parts of a leaf are shown in Figure 4.3. The base of the petiole may have a narrow to broach point of attachment and may obscure the axillary bud. In monocots the petiole is almost always broadly sheathing at the base, and taxa such as grasses (Poaceae) and ginger (Zingiberaceae) have an adaxial flap or ligule at the junction of the sheath and blade. A leaf that lacks a petiole is said to be sessile. A lower pulvinus is usually present and is involved in leaf movement; an upper pulvinus is sometimes present, as in prayer plants (Marantaceae).

Stipules are usually paired appendages located on either side of (or on) the petiole base. Stipules are sometimes single, and are then borne between the petiole and stem. They may be leaflike, scale-like, tendrillike, spine-like, glandular; very reduced, or completely lacking. They have various functions, but most often help in protecting the young leaves. Stipules are not always homologous.

Leaf arrangement Leaves may be arranged in one of three major patterns (Figure 4.4). Alternate leaves are borne singly and are usually arranged in a spiral pattern along the stem. Various kinds of spirals occur, and these can be evaluated by determining the angle around the stem between the points of insertion of any two successive leaves (or by following the spiral around the stem from any older, lower leaf to the first younger leaf directly in line above it). Alternate leaves are sometimes placed along just two sides of the stem (2-ranked, or distichous), or only three sides of the stem (3-ranked, or tristichous). Two-ranked leaves that are flattened in the same plane with both surfaces identical, as in irises (Iridaceae), are called equitant. In contrast, opposite leaves are borne in pairs, the members of which are positioned on opposing sides of the stem. Opposite leaves may be spiraled, 2-ranked, or decussate (the leaves of adjacent nodes rotated 90°); the last is the most common condition among temperate species. Finally, when three or more leaves are positioned at a node, they are considered to be whorled.

Leaf structure A leaf with a single blade is termed simple, while a leaf with two or more blades (leaflets) is said to be compound. The distinction between simple and compound leaves may be made by locating an axillary bud, which is subtended by the entire leaf and by individual leaflets. Leaflets may be arranged in various ways, as shown in Figure 4.5.

Leaf duration Leaves may function from a few days to many years, but most leaves function for only one or two growing seasons. Deciduous leaves fall (are

Figure 4.3 Parts of a generalized angiosperm leaf.

Figure 4.4 The three major patterns of leaf arrangement.
Abscised) at the end of the growing season, while evergreen plants are leafy throughout the year. Some leaves, such as those of many members of Fagaceae, are marcescent; they wither but do not fall off during the winter or dry season.

Venation types If there is one most prominent vein in a leaf, it is called the midvein or primary vein; branches from this vein are called secondary veins. Tertiary veins usually link the secondaries, forming a ladderlike (punctate) or netlike (reticulate) pattern (Figure 4.6).

There are three major patterns of organization of the major veins. The leaf may have a single primary vein with the secondary veins arising along its length like the teeth of a comb; this pattern is termed pinnate. Or the leaf may have several major veins radiating from the base (or near the base) of the blade, like fingers from a palm; this pattern is called palmate. Many different kinds of pinnate (Figure 4.7) and palmate (Figure 4.8)
venation have been characterized (they are discussed in more detail in Hickey 1973 and Dilcher 1974). Finally, the leaf may have many parallel veins, a pattern termed parallel venation (Figure 4.8).

**Leaf shapes** The leaf may be considered to have one of four major shapes (ovate, obovate, elliptic, oblong) depending upon where the blade is the widest (Figure 4.9; Hickey 1973). The meaning of these shape terms may be adjusted by the use of modifiers such as "broadly" or "narrowly." If the petiole is attached away from the leaf margin so that the leaf and its stalk form an "umbrella," the leaf is termed peltate, and such leaves may be any of a number of different shapes. Various other specialized shape terms are sometimes employed, such as linear (for a long and very narrow leaf) or scale-like (for a very small leaf), but the use of such terms is avoided as much as possible here. The blade of a leaf may be symmetrical or asymmetrical when viewed from above.

Very different leaf shapes may occur on the same plant, a condition known as heterophyly. Juvenile leaves may be quite different from adult leaves, but sometimes even an adult plant will bear several different kinds of leaves (as in Sassafras, Lauraceae).

**Leaf apex and base** Various terms relating to the shape of the leaf apex are shown in Figure 4.10; those relating to the shape of the leaf base are illustrated in Figure 4.11.
Leaf margin The leaf blade may be lobed or unlobed. These and other marginal conditions are illustrated in Figure 4.12. Various kinds of marginal teeth may be defined by using anatomic features such as the pattern of the vein or veins entering the tooth, the shape of the tooth, and characters of the tooth apex (such as glandularity). The more common tooth types are illustrated in Figure 4.13; others are defined where first encountered in Chapter 8 (see also Hickey and Wolfe 1975).

Leaf texture The leaf blade may be very thin (membranous), papery in texture (chartaceous), or very thick (coriaceous).

Ptyxis and vernation Ptyxis is the way in which an individual leaf is folded in the bud, while vernation is the way in which leaves are folded in the bud in relation to one another. Leaves that overlap in the bud are termed imbricate, while those with margins merely touching are called valvate. These are vernation terms; a few others are defined in Chapter 8 (in the discussion of particular families). A few ptyxis terms are illustrated in Figure 4.14 (see also Cullen 1978).

Indumentum An indumentum, or covering of hairs (or trichomes), on the surface of an angiosperm gives that surface a particular texture. Most terms describing plant surfaces are ambiguous, and we will use only three here: glabrous (lacking hairs), pubescent (with various hairs), and glaucous (with a waxy covering, and thus often blue or white in appearance). A few terms describing the indumentum are listed below; we will not use them in this text, but, unfortunately, you may encounter them, as well as many others, in botanical keys and descriptions.

- arachnoid having a cobwebby appearance
- canescent gray hairy
- hirsute having long, often stiff, hairs
- hispid having stiff or rough hairs
- lanate woolly
- pilose having scattered, long, slender, soft hairs
- puberulent having minute, short hairs
- scabrous rough
- sericeous silky

Some major tooth types.
Figure 4.14  A few ptyxis terms. All patterns are shown in cross-section except circinate. X indicates the position of the branch bearing the leaf.

- **strigose** having stiff hairs, all pointing in one direction
- **tomentose** having densely matted soft hairs
- **velutinous** velvety
- **villous** covered with long, fine, soft hairs.

We strongly recommend that the kinds of hairs occurring on a plant, along with their distribution and density, be carefully observed under a dissecting (or compound) microscope. Characters derived from such observations usually will be more useful (and consistently applicable) than the indumentum terms listed above. Hairs may be unicellular or multicellular, non-glandular or glandular, and borne singly or in tufts, with surrounding cells of the epidermis modified or not (Figure 4.15). The shape of the individual hairs can be described in detail: Are they branched or simple? How are they branched (dendritic, stellate, T-shaped)? Do they have a flattened or globose head, and is the stalk uniseriate (with one row of

Figure 4.15  Selected features of hairs.

- Unicellular
- Multicellular, uniseriate
- Multicellular, biseriate
- Multicellular, multiseriate
- Gland-headed, 1-celled stalk and head
- Gland head nearly sessile
- Gland head multicellular
- Gland-headed, uniseriate stalk
- Gland-headed, biseriate stalk
- Gland-headed, multiseriate stalk
- Modified basal cell (or cells)
- Hairs clustered
- Stellate
- Stalked, stellate
- T-shaped
- Y-shaped
- With short branches
- Dendritic
- Peltate scale
- Sessile scale