A 1989 survey of distributed file systems can be found in [316]. NFS Versions 2, 3, and 4 are defined

in RFCs 1094, 1813, and 3010, respectively. NFS Version 3 added a number of features, including

support for 64-bit file sizes and offsets, support for asynchronous writes on the server, additional file attributes in many replies, and a readdirplus operation. These extensions allowed the new version

to handle files larger than 2 GB, to improve performance, and to get file handles and attributes along

with file names when scanning a directory. NFS Version 4 borrowed a few features from the Andrew

File System. WebNFS is an extension of NFS Versions 2 and 3; it enables operations through firewalls

and is more easily integrated into Web browsers.

AFS was developed at CMU in collaboration with IBM [250]; it was further developed as an opensource

system by IBM under the name OpenAFS in 2000. Sprite [165] was developed at UC Berkeley

in the mid-1980s. Locus [365] was initially developed at UCLA in the early 1980s and its development

was continued by Locus Computing Corporation. Apollo [211] was developed at Apollo Computer Inc.,

established in 1980 and acquired in 1989 by HP. The Remote File System (RFS) [35] was developed at

Bell Labs in the mid-1980s.

The documentation of a current version of GPFS and an analysis of the caching strategy are given

in GPFS [177] and [317], respectively.

Several generations of DBMSs based on different models have been developed through the years.

In 1968 IBM released the Information Management System (IMS) for IBM 360 computers; IMS was

based on the so-called navigational model, which supported manual navigation in a linked data set

where the data was organized hierarchically. The relational database management system (RDBMS)

model was introduced in 1970 by Codd [87]; in this model related records are linked together and can

be accessed using a unique key. Codd also introduced a tuple calculus as a basis for a query model for

an RDBMS; this led to the development of the Structured Query Language (SQL).

In 1973, the Ingres research project at UC Berkeley developed an RDBMS; several companies,

including Sybase, Informix, NonStop SQL, and Ingres, were established to create SQL RDBMS commercial

products based on the ideas generated by the Ingres project. IBM’s DB2 and SQL/DS dominated

the RDBMS market for main frames during the later years of the 1980s. TheOracleCorporation, founded

in 1977, was also involved in the development of RDBMS.

The ACID properties of database transactions were defined by Jim Gray in 1981 [143] and the term

ACID was introduced in [156].

The object-oriented programming ideas of the 1980s led to the development of object-oriented

database management systems (OODBMSs) in which the information is packaged as objects. The ideas

developed by several research projects, including Encore-Ob/Server at Brown University, Exodus at the

University ofWisconsin at Madison, Iris atHP, ODE at Bell Labs, and theOrion project at MCC-Austin,

helped the development of several OODBMS commercial products [191].

The so-called NoSQL database management systems emerged in the 2000s. They do not follow

the RDBMS model, do not use SQL as a query language, may not give ACID grantees, and have a

distributed, fault-tolerant architecture.