1

Introduction

Learning Objectives

- Scope of soft computing.
- Various components under soft computing.
- Description on artificial neural networks with its advantages and applications.
- An overview of fuzzy logic.
- A note on genetic algorithm.
- The theory of hybrid systems.

1.1 Neural Networks

A neural network is a processing device, either an algorithm or an actual hardware, whose design was inspired by the design and functioning of animal brains and components thereof. The computing world has a lot to gain from neural networks, also known as artificial neural networks or neural net. The neural networks have the ability to learn by example, which makes them very flexible and powerful. For neural networks, there is no need to devise an algorithm to perform a specific task, that is, there is no need to understand the internal mechanisms of that task. These networks are also well suited for real-time systems because of their fast response and computational times which are because of their parallel architecture.

Before discussing artificial neural networks, let us understand how the human brain works. The human brain is an amazing processor. Its exact workings are still a mystery. The most basic element of the human brain is a specific type of cell, known as neuron, which doesn't regenerate. Because neurons aren't slowly replaced, it is assumed that they provide us with our abilities to remember, think and apply previous experiences to our every action. The human brain comprises about 100 billion neurons. Each neuron can connect with up to 200,000 other neurons, although 1,000–10,000 interconnections are typical.

The power of the human mind comes from the sheer numbers of neurons and their multiple interconnections. It also comes from genetic programming and learning. There are over 100 different classes of neurons. The individual neurons are complicated. They have a myriad of parts, subsystems and control mechanisms. They convey information via a host of electrochemical pathways. Together these neurons and their connections form a process which is not binary, not stable, and not synchronous. In short, it is nothing like the currently available electronic computers, or even artificial neural networks.

1.1.1 Artificial Neural Network: Definition

An artificial neural network (ANN) may be defined as an information-processing model that is inspired by the way biological nervous systems, such as the brain, process information. This model tries to replicate only the most basic functions of the brain. The key element of ANN is the novel structure of its information processing system. An ANN is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems.

Artificial neural networks, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification through a learning process. In biological systems, learning involves adjustments to the synaptic connections that exist between the neurons. ANNs undergo a similar change that occurs when the concept on which they are built leaves the academic environment and is thrown into the harsher world of users who simply want to get a job done on computers accurately all the time. Many neural networks now being designed are statistically quite accurate, but they still leave their users with a bad taste as they falter when it comes to solving problems accurately. They might be 85–90% accurate. Unfortunately, few applications tolerate that level of error.

1.1.2 Advantages of Neural Networks

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, could be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. A trained neural network could be thought of as an "expert" in a particular category of information it has been given to analyze. This expert could be used to provide projections in new situations of interest and answer "what if" questions. Other advantages of working with an ANN include:

1. *Adaptive learning*: An ANN is endowed with the ability to learn how to do tasks based on the data given for training or initial experience.
2. *Self-organization*: An ANN can create its own organization or representation of the information it receives during learning time.
3. *Real-time operation*: ANN computations may be carried out in parallel. Special hardware devices are being designed and manufactured to take advantage of this capability of ANNs.
4. *Fault tolerance via redundant information coding*: Partial destruction of a neural network leads to the corresponding degradation of performance. However, some network capabilities may be retained even after major network damage.

Currently, neural networks can't function as a user interface which translates spoken words into instructions for a machine, but someday they would have this skill. Then VCRs, home security systems, CD players, and word processors would simply be activated by voice. Touch screen and voice editing would replace the word processors of today. Besides, spreadsheets and databases would be imparted such level of usability that would be pleasing to everyone. But for now, neural networks are only entering the marketplace in niche areas where their statistical accuracy is valuable.

Many of these niches indeed involve applications where answers provided by the software programs are not accurate but vague. Loan approval is one such area. Financial institutions make more money if they succeed in having the lowest bad loan rate. For these institutions, installing systems that are "90% accurate" in selecting the genuine loan applicants might be an improvement over their current selection process. Indeed, some banks have proved that the failure rate on loans approved by neural networks is lower than those approved by their best traditional methods. Also, some credit card companies are using neural networks in their application screening process.

This newest method of looking into the future by analyzing past experiences has generated its own unique set of problems. One such problem is to provide a reason behind a computer-generated answer, say, as to why a particular loan application was denied. To explain how a network learned and why it recommends a particular decision has been difficult. The inner workings of neural networks are "black boxes." Some people have even called the use of neural networks "voodoo engineering." To justify the decision-making process, several neural network tool makers have provided programs that explain which input through which node dominates the decision-making process. From this information, experts in the application may be able to infer which data plays a major role in decision-making and its importance.

Apart from filling the niche areas, neural network's work is also progressing in other more promising application areas. The next section of this chapter goes through some of these areas and briefly details the current work. The objective is to make the reader aware of various possibilities where neural networks might offer solutions, such as language processing, character recognition, image compression, pattern recognition, etc.

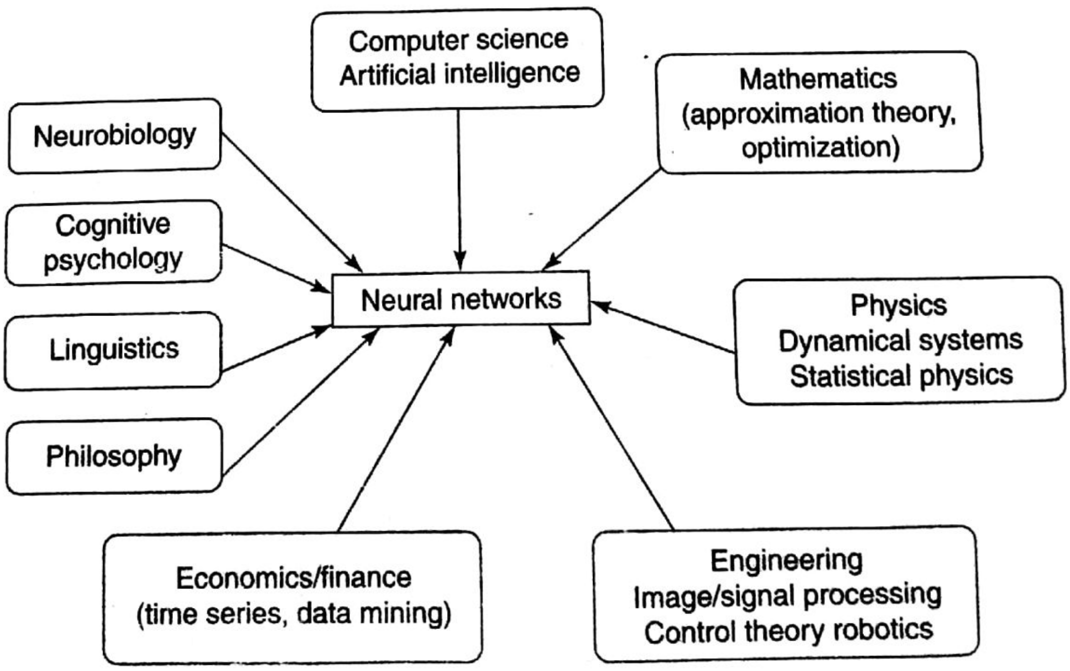

Figure 1-1 The multi-disciplinary point of view of neural networks.

Neural networks can be viewed from a multi-disciplinary point of view as shown in Figure 1-1.

1.2 Application Scope of Neural Networks

The neural networks have good scope of being used in the following areas:

1. *Air traffic control* could be automated with the location, altitude, direction and speed of each radar blip taken as input to the network. The output would be the air traffic controller's instruction in response to each blip.
2. *Animal behavior*, predator/prey relationships and population cycles may be suitable for analysis by neural networks.
3. *Appraisal and valuation* of property, buildings, automobiles, machinery, etc., should be an easy task for a neural network.
4. *Betting* on horse races, stock markets, sporting events, etc., could be based on neural network predictions.
5. *Criminal sentencing* could be predicted using a large sample of crime details as input and the resulting sentences as output.
6. *Complex physical and chemical processes* that may involve the interaction of numerous (possibly unknown) mathematical formulas could be modeled heuristically using a neural network.
7. *Data mining, cleaning and validation* could be achieved by determining which records suspiciously diverge from the pattern of their peers.
8. *Direct mail advertisers* could use neural network analysis of their databases to decide which customers should be targeted, and avoid wasting money on unlikely targets.
9. *Echo patterns* from sonar, radar, seismic and magnetic instruments could be used to predict their targets.
10. *Econometric modeling* based on neural networks should be more realistic than older models based on classical statistics.
11. *Employee hiring* could be optimized if the neural networks were able to predict which job applicant would show the best job performance.
12. *Expert consultants* could package their intuitive expertise into a neural network to automate their services.
13. *Fraud detection* regarding credit cards, insurance or taxes could be automated using a neural network analysis of past incidents.
14. *Handwriting and typewriting* could be recognized by imposing a grid over the writing, then each square of the grid becomes an input to the neural network. This is called "Optical Character Recognition."
15. *Lake water levels* could be predicted based upon precipitation patterns and river/ dam flows.
16. *Machinery control* could be automated by capturing the actions of experienced machine operators into a neural network.

17. *Medical diagnosis* is an ideal application for neural networks.
18. *Medical research* relies heavily on classical statistics to analyze research data. Perhaps a neural network should be included in the researcher's tool kit.
19. *Music composition* has been tried using neural networks. The network is trained to recognize patterns in the pitch and tempo of certain music, and then the network writes its own music.
20. *Photos and fingerprints* could be recognized by imposing a fine grid over the photo. Each square of the grid becomes an input to the neural network.
21. *Recipes and chemical formulations* could be optimized based on the predicted outcome of a formula change.
22. *Retail inventories* could be optimized by predicting demand based on past patterns.
23. *River water levels* could be predicted based on upstream reports, and time and location of each report.
24. *Scheduling of buses, airplanes and elevators* could be optimized by predicting demand.
25. *Staff scheduling* requirements for restaurants, retail stores, police stations, banks, etc., could be predicted based on the customer flow, day of week, paydays, holidays, weather, season, etc.
26. *Strategies* for games, business and war can be captured by analyzing the expert player's response to given stimuli. For example, a football coach must decide whether to kick, pass or run on the last down. The inputs for this decision include score, time, field location, yards to first down, etc.
27. *Traffic flows* could be predicted so that signal timing could be optimized. The neural network could recognize "a weekday morning rush hour during a school holiday" or "a typical winter Sunday morning."
28. *Voice recognition* could be obtained by analyzing the audio oscilloscope pattern, much like a stock market graph.
29. *Weather prediction* may be possible. Inputs would include weather reports from surrounding areas. Output(s) would be the future weather in specific areas based on the input information. Effects such as ocean currents and jet streams could be included.

Today, ANN represents a major extension to computation. Different types of neural networks are available for various applications. They perform operations akin to the human brain though to a limited extent. A rapid increase is expected in our understanding of the ANNs leading to the improved network paradigms and a host of application opportunities.

1.3 Fuzzy Logic

The concept of fuzzy logic (FL) was conceived by Lotfi Zadeh, a Professor at the University of California at Berkeley. An organized method for dealing with imprecise data is called fuzzy logic. The data are considered as fuzzy sets.

Professor Zadeh presented FL not as a control methodology but as a way of processing data by allowing partial set membership rather than crisp set membership or nonmembership.

This approach to set theory was not applied to control systems until the 1970s due to insufficient computer capability. Also, earlier the systems were designed only to accept precise and accurate data. However, in certain systems it is not possible to get the accurate data. Therefore, Professor Zadeh reasoned that for processing need not always require precise and numerical information input; processing can be performed even with imprecise inputs. Suitable feedback controllers may be designed to accept noisy, imprecise input, and they would be much more effective and perhaps easier to implement. The processing with imprecise inputs led to the growth of Zadeh's FL. Unfortunately, US manufacturers have not been so quick to embrace this technology while the Europeans and Japanese have been aggressively building real products around it.

Fuzzy logic is a superset of conventional (or Boolean) logic and contains similarities and differences with Boolean logic. FL is similar to Boolean logic in that Boolean logic results are returned by FL operations when all fuzzy memberships are restricted to 0 and 1. FL differs from Boolean logic in that it is permissive of natural language queries and is more like human thinking; it is based on degrees of truth. For example, traditional sets include or do not include an individual element; there is no other case than true or false. However, fuzzy sets allow partial membership. FL is basically a multivalued logic that allows intermediate values to be defined between conventional evaluations such as *yes/no*, *true/false*, *black/white*, etc. Notions like rather warm or pretty cold can be formulated mathematically and processed with the computer. In this way, an attempt is made to apply a more human-like way of thinking in the programming of computers.

Fuzzy logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded microcontrollers to large, networked, multichannel PC or workstation-based data acquisition and control systems. It can be implemented in hardware, software or a combination of both. FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. FL's approach to control problems mimics how a person would make decisions, only much faster.

4 Genetic Algorithm

Genetic algorithm (GA) is reminiscent of sexual reproduction in which the genes of two parents combine to form those of their children. When it is applied to problem solving, the basic premise is that we can create an initial population of individuals representing possible solutions to a problem we are trying to solve. Each of these individuals has certain characteristics that make them more or less fit as members of the population. The more fit members will have a higher probability of mating and producing offspring that have a significant chance of retaining the desirable characteristics of their parents than the less fit members. This method is very effective at finding optimal or near-optimal solutions to a wide variety of problems because it does not impose many limitations required by traditional methods. It is an elegant generate-and-test strategy that can identify and exploit regularities in the environment, and results in solutions that are globally optimal or nearly so.

Genetic algorithms are adaptive computational procedures modeled on the mechanics of natural genetic systems. They express their ability by efficiently exploiting the historical information to speculate on new offspring with expected improved performance. GAs are executed iteratively on a set of coded solutions, called population, with three basic operators:

selection/reproduction, crossover and mutation. They use only the payoff (objective function) information and probabilistic transition rules for moving to the next iteration. They are different from most of the normal optimization and search procedures in the following four ways:

1. GAs work with the coding of the parameter set, not with the parameter themselves;
2. GAs work simultaneously with multiple points, not a single point;
3. GAs search via sampling (a blind search) using only the payoff information;
4. GAs search using stochastic operators, not deterministic rules.

Since a GA works simultaneously on a set of coded solutions, it has very little chance to get stuck at local optima when used as optimization technique. Again, it does not need any sort of auxiliary information, like derivative of the optimizing function. Moreover, the resolution of the possible search space is increased by operating on coded (possible) solutions and not on the solutions themselves. Further, this search space need not be continuous. Recently, GAs are finding widespread applications in solving problems requiring efficient and effective search, in business, scientific and engineering circles like synthesis of neural network architectures, traveling salesman problem, graph coloring, scheduling, numerical optimization, and pattern recognition and image processing.

1.5 Hybrid Systems

Hybrid systems can be classified into three different systems: Neuro fuzzy hybrid system; neuron genetic hybrid system; fuzzy genetic hybrid systems. These are discussed in detail in the following sections.

1.5.1 *Neuro Fuzzy Hybrid Systems*

A neuro fuzzy hybrid system is a fuzzy system that uses a learning algorithm derived from or inspired by neural network theory to determine its parameters (fuzzy sets and fuzzy rules) by processing data samples.

In other words, a neuro fuzzy hybrid system refers to the combination of fuzzy set theory and neural networks having advantages of both which are listed below.

1. It can handle any kind of information (numeric, linguistic, logical, etc.).
2. It can manage imprecise, partial, vague or imperfect information.
3. It can resolve conflicts by collaboration and aggregation.
4. It has self-learning, self-organizing and self-tuning capabilities.
5. It doesn't need prior knowledge of relationships of data.
6. It can mimic human decision-making process.
7. It makes computation fast by using fuzzy number operations.

Neuro fuzzy hybrid systems combine the advantages of fuzzy systems, which deal with explicit knowledge that can be explained and understood, and neural networks, which deal with implicit knowledge that can be acquired by learning. Neural network learning provides a good way to adjust the knowledge of the expert (i.e., artificial intelligence system) and automatically generate additional fuzzy rules and membership functions to meet certain specifications. It helps reduce design time and costs. On the other hand, FL enhances the generalization capability of a neural network system by providing more reliable output when extrapolation is needed beyond the limits of the training data.

1.5.2 Neuro Genetic Hybrid Systems

Genetic algorithms (GAs) have been increasingly applied in ANN design in several ways: topology optimization, genetic training algorithms and control parameter optimization. In topology optimization, GA is used to select a topology (number of hidden layers, number of hidden nodes, interconnection pattern) for the ANN which in turn is trained using some training scheme, most commonly back propagation. In genetic training algorithms, the learning of an ANN is formulated as a weight optimization problem, usually using the inverse mean squared error as a fitness measure. Many of the control parameters such as learning rate, momentum rate, tolerance level, etc., can also be optimized using GAs. In addition, GAs have been used in many other innovative ways, to create new indicators based on existing ones, select good indicators, evolve optimal trading systems and complement other techniques such as fuzzy logic.

1.5.3 Fuzzy Genetic Hybrid Systems

The optimization abilities of GAs are used to develop the best set of rules to be used by a fuzzy inference engine, and to optimize the choice of membership functions. A particular use of GAs is in fuzzy classification systems, where an object is classified on the basis of the linguistic values of the object attributes. The most difficult part of building a system like this is to find the appropriate set of fuzzy rules. The most obvious approach is to obtain knowledge from experts and translate this into a set of fuzzy rules. But this approach is time consuming. Besides, experts may not be able to put their knowledge into an appropriate form of words. A second approach is to obtain the fuzzy rules through machine learning, whereby the knowledge is automatically extracted or deduced from sample cases. A fuzzy GA is a directed random search over all (discrete) fuzzy subsets of an interval and has features which make it applicable to solving this problem. It is capable of creating the classification rules for a fuzzy system where objects are classified by linguistic terms. Coding the rules genetically enables the system to deal with multivalue FL and is more efficient as it is consistent with numeric coding of fuzzy examples. The training data and randomly generated rules are combined to create the initial population, giving a better starting point for reproduction. Finally, a fitness function measures the strength of the rules, balancing the quality and diversity of the population.

1.6 Soft Computing

The two major problem-solving technologies include:

1. hard computing;
2. soft computing.

Hard computing deals with precise models where accurate solutions are achieved quickly. On the other hand, soft computing deals with approximate models and gives solution to complex problems. The two problem-solving technologies are shown in Figure 1-2.

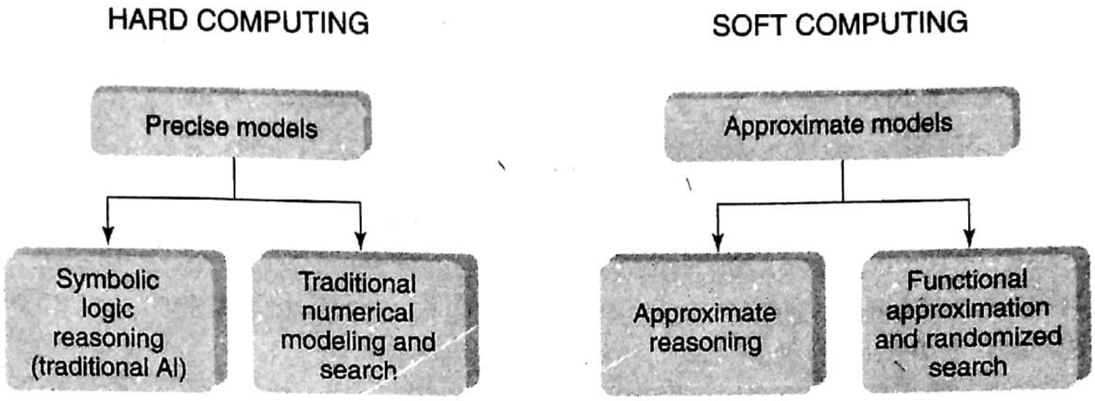

Figure 1-2 Problem-solving technologies.

Soft computing is a relatively new concept, the term really entering general circulation in 1994. The term "soft computing" was introduced by Professor Lotfi Zadeh with the objective of exploiting the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness, low solution cost and better rapport with reality. The ultimate goal is to be able to emulate the human mind as closely as possible. Soft computing involves partnership of several fields, the most important being neural networks, GAs and FL. Also included is the field of probabilistic reasoning, employed for its uncertainty control techniques. However, this field is not examined here.

Soft computing uses a combination of GAs, neural networks and FL. A hybrid technique, in fact, would inherit all the advantages, but won't have the less desirable features of single soft computing components. It has to possess a good learning capacity, a better learning time than that of pure GAs and less sensitivity to the problem of local extremes than neural networks. In addition, it has to generate a fuzzy knowledge base, which has a linguistic representation and a very low degree of computational complexity.

An important thing about the constituents of soft computing is that they are complementary, not competitive, offering their own advantages and techniques to partnerships to allow solutions to otherwise unsolvable problems. The constituents of soft computing are examined in turn, following which existing applications of partnerships are described.

"Negotiation is the communication process of a group of agents in order to reach a mutually accepted agreement on some matter." This definition is typical of the research being done into negotiation and co-ordination in relation to software agents. It is an obvious necessity that when multiple agents interact, they will be required to co-ordinate their efforts and attempt to sort out any conflicts of resources or interest.

It is important to appreciate that agents are owned and controlled by people in order to complete tasks on their behalf. An example of a possible multiple-agent-based negotiation scenario is the competition between long-distance phone call providers. When the consumer picks up the phone and dials, an agent will communicate on the consumer's behalf with all the available network providers. Each provider will make an offer that the consumer agent can accept or reject. A realistic goal would be to select the lowest available price for the call. However, given the first round of offers, network providers may wish to modify their offer to make it more competitive. The new offer is then submitted to the consumer agent and the process continues until a conclusion is reached. One advantage of this process is that the provider can dynamically alter its pricing strategy to account for changes in demand and competition, therefore maximizing revenue. The consumer will obviously benefit from the constant competition between providers. Best of all, the process is entirely autonomous as the agents embody and act on the beliefs and constraints of the parties they represent. Further changes can be made to the protocol so that providers can bid low without being in danger of making a loss. For example, if the consumer chooses to go with the lowest bid but pays the second lowest price, this will take away the incentive to underbid or overbid.

Much of the negotiation theory is based around human behavior models and, as a result, it is often translated using Distributed Artificial Intelligence techniques. The problems associated with machine negotiation are as difficult to solve as they are with human negotiation and involve issues such as privacy, security and deception.

1.7 Summary

The computing world has a lot to gain from neural networks whose ability to learn by example makes them very flexible and powerful. In case of neural networks, there is no need to devise an algorithm to perform a specific task, i.e., there is no need to understand the internal mechanisms of that task. Neural networks are also well suited for real-time systems because of their fast response and computational times, which are due to their parallel architecture.

Neural networks also contribute to other areas of research such as neurology and psychology. They are regularly used to model parts of living organisms and to investigate the internal mechanisms of the brain. Perhaps the most exciting aspect of neural networks is the possibility that someday "conscious" networks might be produced. Today, many scientists believe that consciousness is a "mechanical" property and that "conscious" neural networks are a realistic possibility.

Fuzzy logic was conceived as a better method for sorting and handling data but has proven to be an excellent choice for many control system applications since it mimics human control logic. It can be built into anything from small, hand-held products to large, computerized process control systems. It uses an imprecise but very descriptive language to deal with input data more like a human operator. It is robust and often works when first implemented with little or no tuning.

When applied to optimize ANNs for forecasting and classification problems, GAs can be used to search for the right combination of input data, the most suitable forecast horizon, the optimal or near-optimal network interconnection patterns and weights among the neurons, and the control parameters (learning rate, momentum rate, tolerance level, etc.) based on the training data used and the pre-set criteria. Like ANNs, GAs do not always guarantee you a perfect solution, but in many cases, you can arrive at an acceptable solution without the time and expense of an exhaustive search.

Soft computing is a relatively new concept, the term really entering general circulation in 1994, coined by Professor Lotfi Zadeh of the University of California, Berkeley, USA, it encompasses several fields of computing. The three that have been examined in this chapter are neural networks, FL and GAs. Neural networks are important for their ability to adapt and learn, FL for its exploitation of partial truth and imprecision, and GAs for their application to optimization. The field of probabilistic reasoning is also sometimes included under the soft computing umbrella for its control of randomness and uncertainty. The importance of soft computing lies in using these methodologies in partnership – they all offer their own benefits which are generally not competitive and can therefore, work together. As a result, several hybrid systems were looked at – systems in which such partnerships exist.