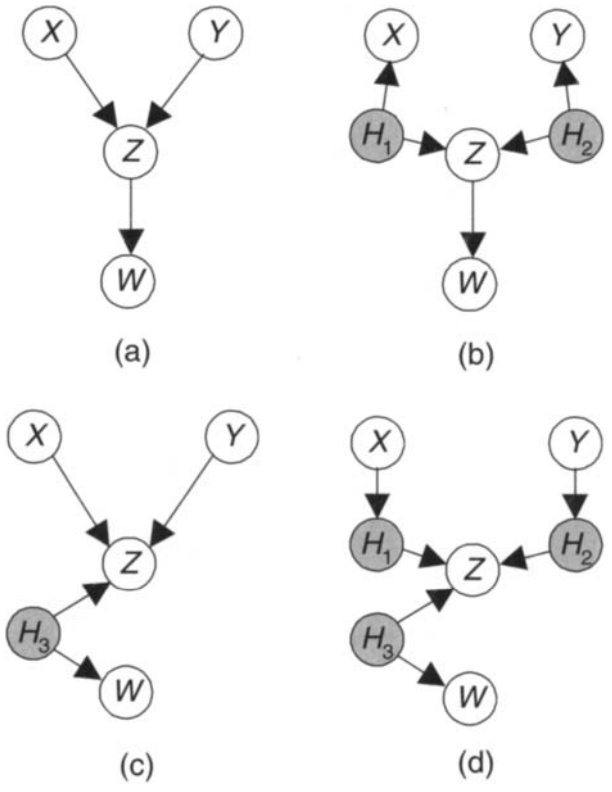


Figure 4.22: If our set of conditional independencies is $\{I_P(X,Y), I_P(W,\{X,Y\}|Z)\}$, then $P$ is embedded faithfully in the DAGs in (a) and (b), but not in the DAGs in (c) and (d).

*4.23 (c). P is also embedded faithfully in the DAG in Figure 4.23 (b). If we make the causal embedded faithfulness assumption, we conclude that Z and W have a hidden common cause.*

## 4.6 Software Packages for Learning

Based on considerations such as those illustrated in Section 4.4.1, Spirtes et al. [1993, 2000] developed an algorithm which finds the DAG faithful to $P$ from the conditional independencies in $P$ when there is a DAG faithful to $P$. Spirtes et al. [1993, 2000] further developed an algorithm which learns a DAG in which $P$ is embedded faithfully from the conditional independencies in $P$ when such a DAG exists. These algorithms have been implemented in the Tetrad software package [Scheines et al., 1994], which can be downloaded for free from the following site:

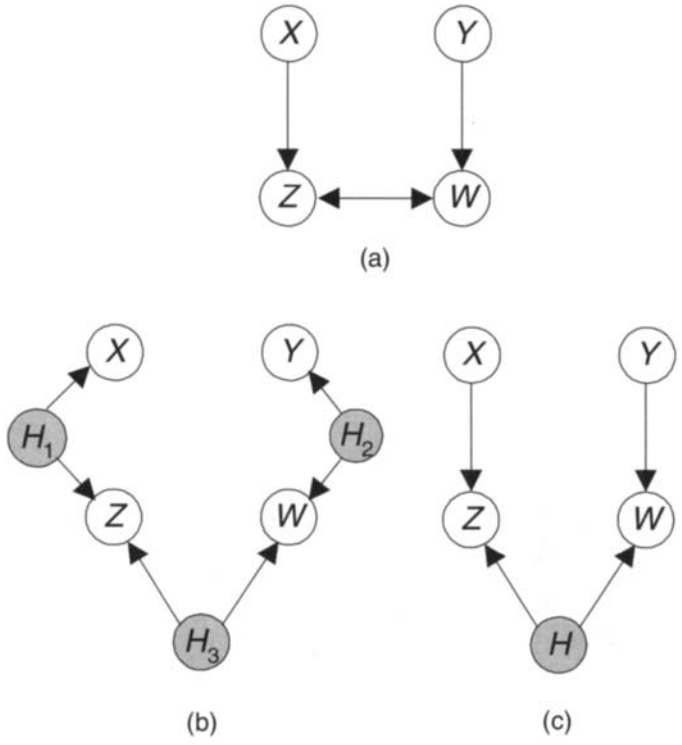


Figure 4.23: If our set of conditional independencies is $\{I_P(X, \{Y, W\}), I_P(Y, \{X, Z\})$, we can conclude that $Z$ and $W$ have a hidden common cause.

http://www.phil.cmu.edu/projects/tetrad/.

In 1997 Meek developed a heuristic search algorithm called **Greedy Equivalent Search (GES)** which has the following property: if there were a DAG faithful to $P$, the limit, as the size of the data set approaches infinity, of the probability of finding a DAG faithful to $P$ is equal to 1. The Tetrad software package also has a module which uses that algorithm along with the **Bayesian information criterion (BIC)** to learn a Bayesian network from data.

Other Bayesian network learning packages include the following:

1. Belief Network Power Constructor (constraint-based approach), http://www.cs.ualberta.ca/~jcheng/bnpc.htm.
2. Bayesware (structure and parameters), http://www.bayesware.com/.
3. Bayes Net Toolbox, http://bnt.sourceforge.net/.
4. Probabilistic Net Library, http://www.intel.com/technology/computing/pnl/.