ArcGIS® Schematics: Dealing with Connectivity

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ESRI 380 New York St., Redlands, CA 92373-8100 USA • TEL 909-793-2853 • FAX 909-793-5953 • E-MAIL info@esri.com • WEB www.esri.com

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An ESRI White Paper

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ArcGIS Schematics: Dealing with Connectivity

Introduction

Connectivity and relationships are key information for managing and viewing networks, which are a way to use any event occurring between objects and view all the information in an organized manner that is easy to analyze and understand. Connectivity can represent different varieties of information and can be used to generate diagrams that show how entities are related.

There are so many different types of networks that connectivity represents a large diversity of relationships. Networks can be categorized in different manners, but there are two main families:

- Physical networks—Energy (gas, electricity), communications (telecommunications, cable, cyber networks), pipeline (oil and gas), water supply and wastewater, transportation (road, rail), and so forth

- Logical and social networks—Health and agriculture (animal and disease tracking), homeland security (critical infrastructure, interdependencies analysis), law enforcement (crime scene analysis), finance (flow charts), telecommunications (services analysis), and so forth

The distinction between physical and logical networks is hard to define, and it makes sense to merge these types to be able to use physical and logical relations within a unique schematic diagram.

As a consequence of the needs discussed above, connectivity events can appear in various manners such as

- Physical connections—Pipe 1 *connects* valve A to valve B.
- Logical connections—Substation A *feeds* hospital B.
- Flow—The power *is going* from power plant A to substation B.
- Relational—Mr. A *likes* Mrs. B.
- Factual—The list of users *was sent* by Mr. A to Mrs. B.
- Physical—Cow 1 *moves* from ranch A to ranch B.
- Hierarchical—Mr. A *reports* to Mrs. B.
- Ownership—House A *is owned* by Mrs. B.
- Time—Flight 131 *departure time* is 2:00 p.m. and *arrival time* is 3:30 p.m.
- Spatial—Transformers 1, 3, and 4 *are within* substation A.

Users store and manage connectivity information in many different ways. Some use physical connectivity, such as the geometric network, while others use information stored in database tables.

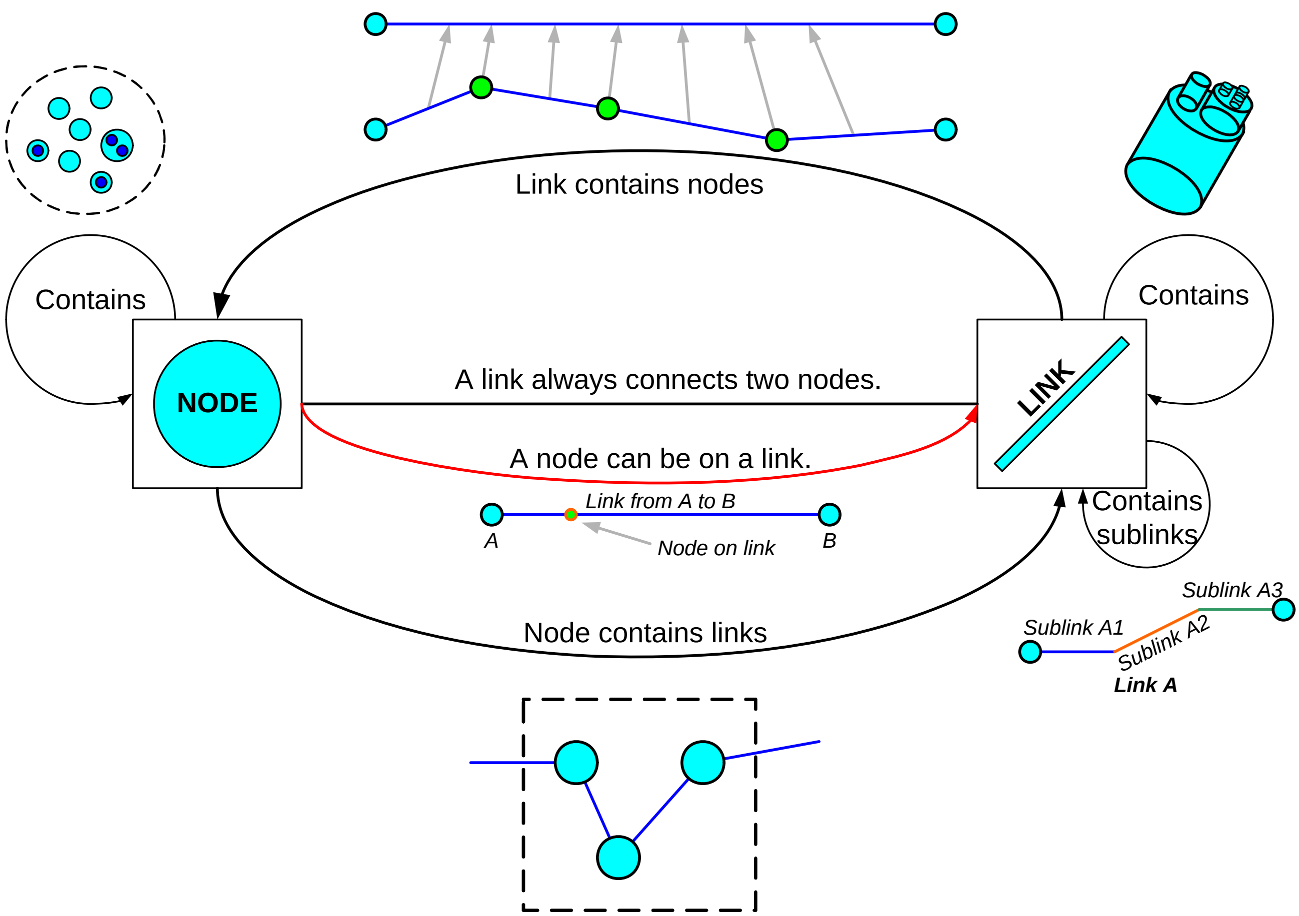
This document gives an overview of the ArcGIS® Schematics metamodel and discusses how these different types of connectivity are managed within the application.

Since connectivity is managed through the Schematics Designer application, it is advisable to read the white paper *ArcGIS Schematics: Automatic Schematic Generation for ArcGIS* prior to reading this one.

The ArcGIS Schematics Network Metamodel

The metamodel is an important piece of the ArcGIS Schematics extension since it must be generic and recursive to manage all aspects of connectivity. The two main objects are the node and the link. Links represent the relationships between nodes. Figure 1 shows how connectivity can be represented within a schematic diagram.

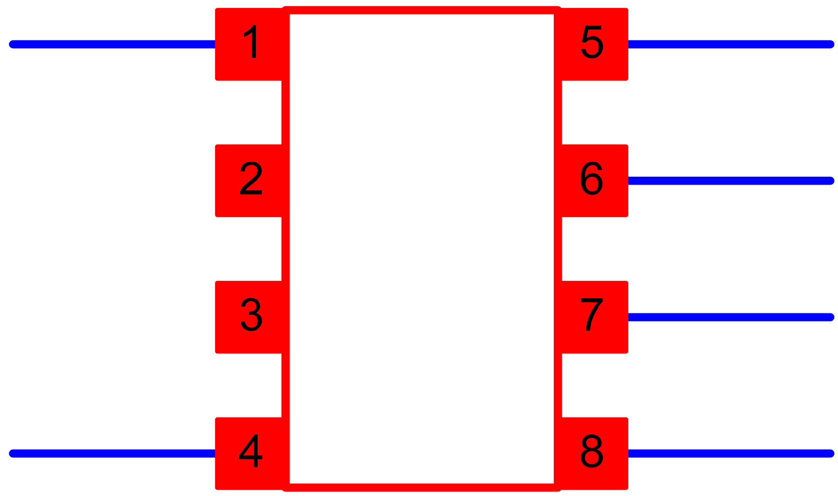
Figure 1
ArcGIS Schematics Network Model



A node is a junction in a network graph. It is represented by a symbol and may be assigned various graphic (color, fill style, and so forth), geometric (e.g., scaling and rotation), or visual (visibility, highlighting, etc.) attributes. A node on a link is a node positioned on a link path route. Its location on the link is either absolute or relative. Nodes on links are completely dependent on the link to which they are related.

Some applications request the ability to have many connection ports to a node. ArcGIS Schematics allows the setting of ports to a symbol that represents a node (see figure 2).

Figure 2
Node with Multiple Connection Ports



A link is an edge in a network graph. It is represented by either a direct single line segment or several line segments passing through zero or many link points. A link can have a direction; arrows (pattern models) can be placed on its endpoints to show this.

A sublink is a link that exists as part of another link. It connects one node on link to one of its related link's extremity nodes or connects two nodes on links. Sublinks are completely dependent on the link to which they are related.

Connectivity Managed in the Geodatabase

Physical Connectivity

Physical connectivity is stored in the geodatabase as either a geometric network or a network dataset. ArcGIS Schematics can read both networks, retrieve the connectivity, and generate a diagram that is stored in the geodatabase in a schematics dataset.

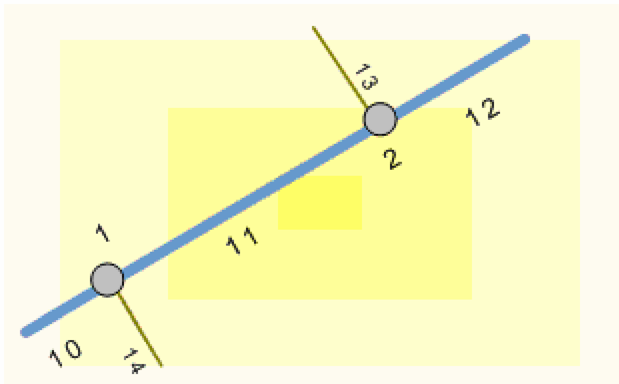
Geometric Networks

Geometric networks offer a way to model common networks and infrastructures found in the real world. Water distribution, electrical lines, gas pipelines, telephone services, and water flow in a stream are examples of resource flows that can be modeled and analyzed using a geometric network.

A geometric network is a set of connected edges and junctions along with connectivity rules that are used to represent and model the behavior of a common network infrastructure in the real world. Geodatabase feature classes are used as the data sources to define the geometric network. You define the roles that various features will play in the geometric network and rules for how resources flow through the geometric network.

In figure 3, a geometric network models the flow of water through water mains and services that are connected by water junction fittings.

Figure 3
Water Geometric Network



Water Junction Fittings (Points)

OID	hape	Equip ID	Valve Type
1		816-32	T203
2		816-45	Y53

Water Mains (Lines)

OID	Shape	Diameter	Material
10		8	Concrete
11		10	PVC
12		8	Concrete

Water Services (Lines)

OID	Shape	Service ID	Material
13		1001	Cast iron
14		1002	Copper

A utility network can be directed. This means the agent (for example, water, sewage, or electricity) flows along the network based on certain rules built into the network. The path that the water will take is predetermined. It can be changed, but not by the agent. The engineer controlling the network can change the rules of the network by opening some valves and closing others to change the direction of the network.

In ArcGIS, utility networks are modeled using geometric networks. To find out more about the geometric network, refer to the geometric_networks.chm file found in the ArcGIS Desktop Help.

The left part of figure 4 shows the result of a trace (in blue) that was generated by using a geometric network on a pipeline network. The right part shows the related schematic diagram that used the geometric network to retrieve the connectivity.

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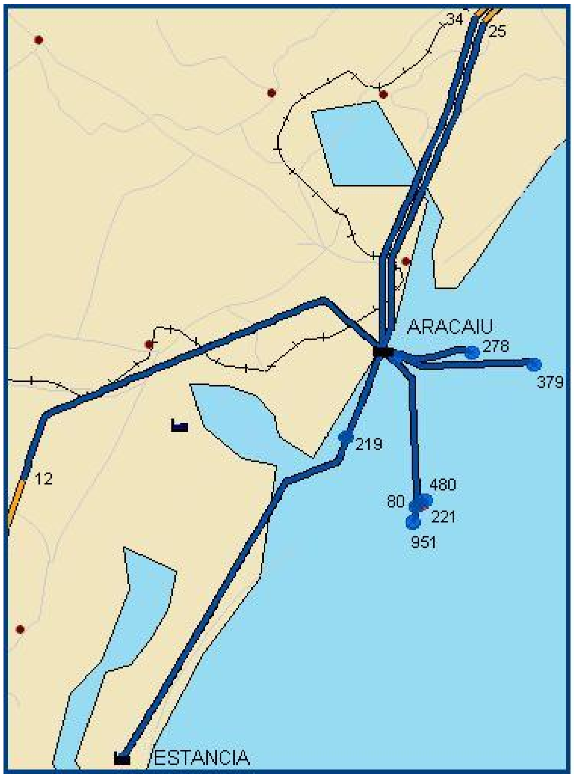
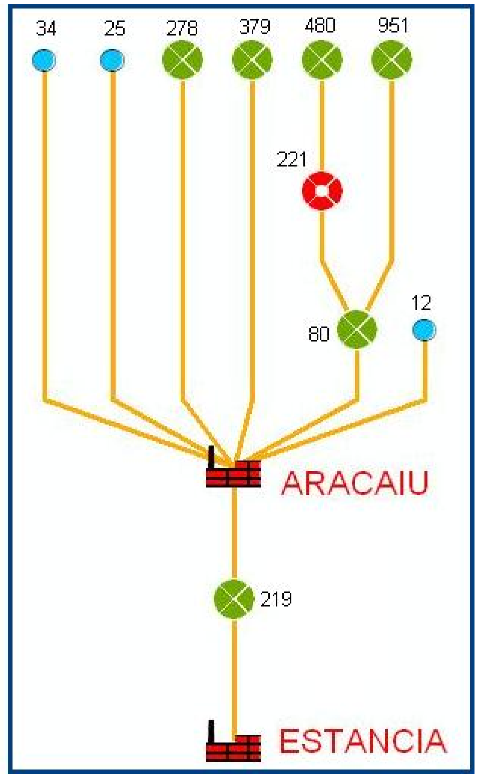
Figure 4
Pipeline Network in Brazil



Trace on a Map



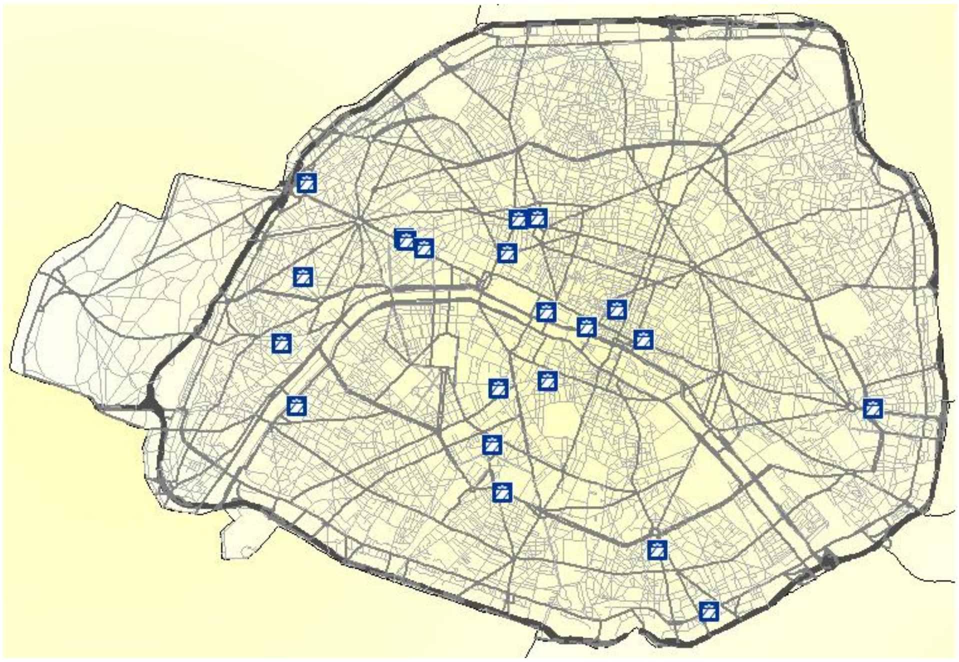
Related Schematic Diagram

The schematic configuration is automatically built using the Import From Feature Classes/Tables tool that is provided in the Schematics Designer application. The connectivity is automatically retrieved from the geometric network.

Network Dataset

The ArcGIS Network Analyst extension allows you to build and perform analysis on a network dataset. A network dataset is created from the feature source or sources that participate in the network. It incorporates an advanced connectivity model that can represent complex scenarios such as multimodal transportation networks. It also possesses a rich network attribute model that helps model impedances, restrictions, and hierarchy for the network. The network dataset is built from simple features (lines and points) and turns. Figure 5 is an example of a transportation network in downtown Paris, France, displaying road, rail, and bus networks.

Figure 5
Paris Transportation Network

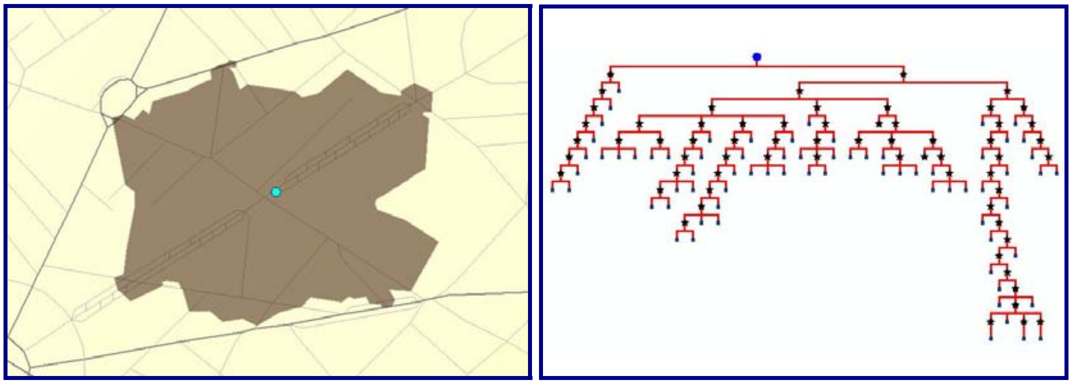


Connectivity is inherently important to travel through the network. Network elements, such as edges (lines) and junctions (points), must be interconnected to allow navigation over the network. Additionally, these elements have properties that control navigation on the network. Transportation networks are undirected networks. This means that although an edge on a network may have a direction assigned to it, the agent (the person or resource being transported) is free to decide the direction, speed, and destination of traversal. For example, a person in a car traveling on a street can choose which street to turn onto, when to stop, and which direction to drive. Restrictions imposed on a network, such as one-way streets or no U-turns allowed, are guidelines for the agent to follow. This is in stark contrast to the utility network.

In ArcGIS, transportation networks are modeled using network datasets. To learn more about the network dataset, refer to the network_analyst.chm file found in the ArcGIS Desktop Help.

The left part of figure 6 shows the result of a service area analysis that was generated with ArcGIS Network Analyst on the Paris transportation network. The right part shows the related tree schematic diagram that used the network dataset to retrieve the transportation network and the connectivity.

Figure 6
Service Area in the City of Paris



Service Area Analysis *Related Schematic Diagram*

The schematic configuration is automatically built when using Network Dataset Builder in the Schematics Designer application. The connectivity is automatically retrieved from the network dataset.

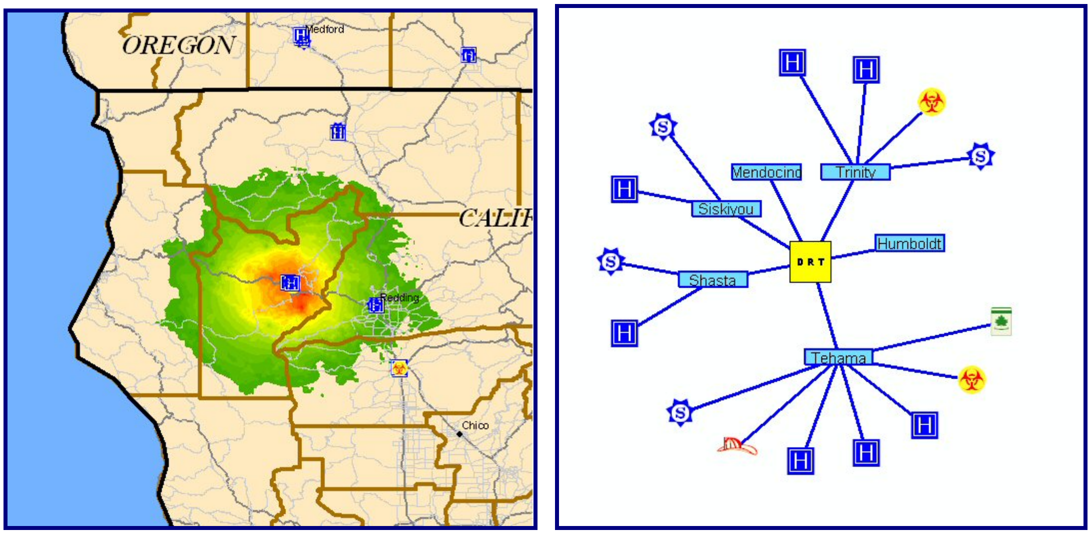
Spatial Connectivity

Spatial connectivity is stored in the geodatabase through topology or can be generated using the Select By Location tool in ArcMap™. ArcGIS Schematics does not use the internal topology that can be created in ArcCatalog™; however, it does include a spatial query rule that invokes the Select By Location tool when generating or updating a schematic diagram. Such a rule is set in the Schematics Designer application at the level of a schematic diagram type.

The Select By Location dialog box lets you select features based on their locations relative to other features. For instance, if you want to know how many homes were affected by a recent flood and you mapped the flood boundary, you could select all the homes that are within this area. This type of question is known as a spatial query.

The map on the left of figure 7 shows an earthquake area in northern California. Using this earthquake polygon, a spatial query rule, and a set of relationship rules (see the Relational Connectivity section), ArcGIS Schematics automatically generated the diagram on the right that shows the disaster response team and all counties that were affected by the earthquake along with their emergency agencies.

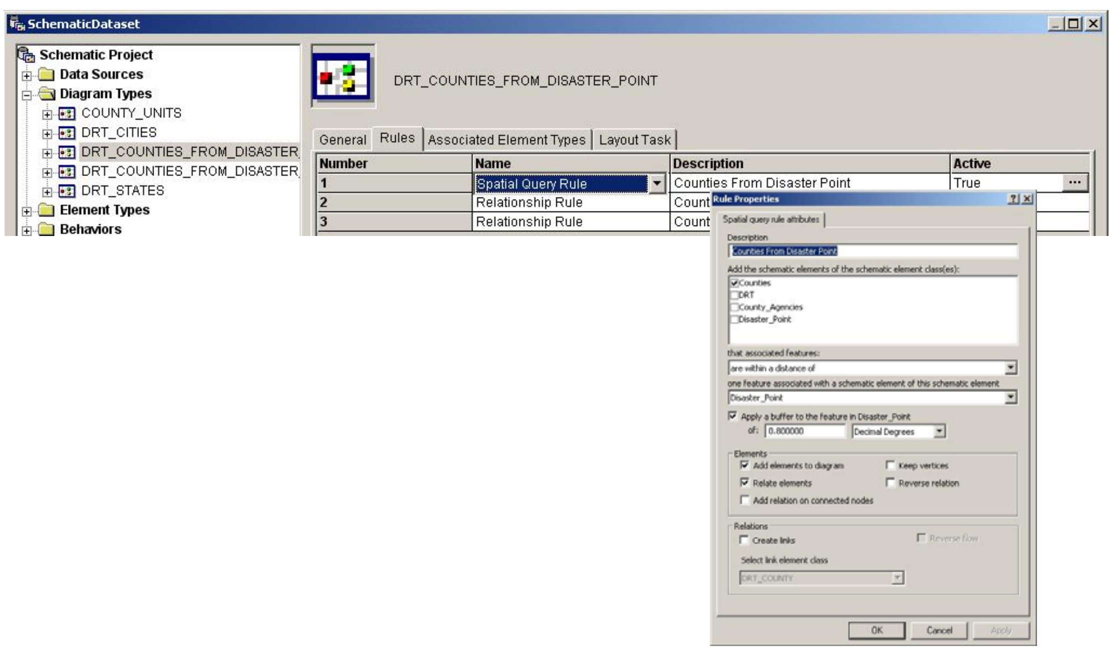
Figure 7
Disaster Management



Earthquake Map *Related County Agencies Diagram*

Figure 8 shows how the spatial query rule is set in the Schematics Designer application.

Figure 8
Spatial Query Rule in Designer



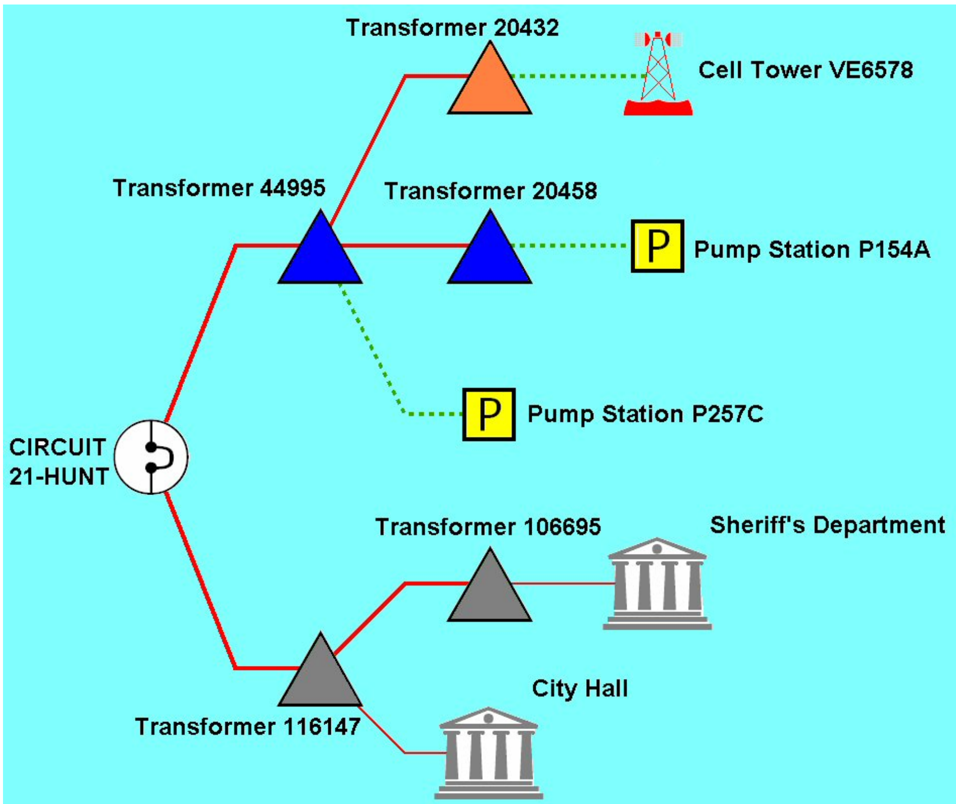
Relational Connectivity

Relationship classes define relationships between objects in the geodatabase. These relationships can be simple one-to-one relationships, similar to what you might create between a feature and a row in a table, or more complex one-to-many or many-to-many relationships between features and table rows. Some relationships specify that a given feature, row, or table is not only related to another feature but that creating, editing, or deleting one will have a specified effect on the other. These are called composite relationships, and they can be used to ensure that the links between objects in the database are maintained and up-to-date.

ArcGIS Schematics includes a relationship rule that uses relationship classes to generate connectivity. Relationship classes are created using ArcCatalog. Then a relationship rule is set in the Schematics Designer application at the level of a schematic diagram type and is invoked each time a diagram is created or updated.

Figure 9 below shows a diagram that was generated by using a geometric network of an electrical network and a set of relationship classes set between the electrical transformers (triangles) and cell towers, pump stations, and critical buildings.

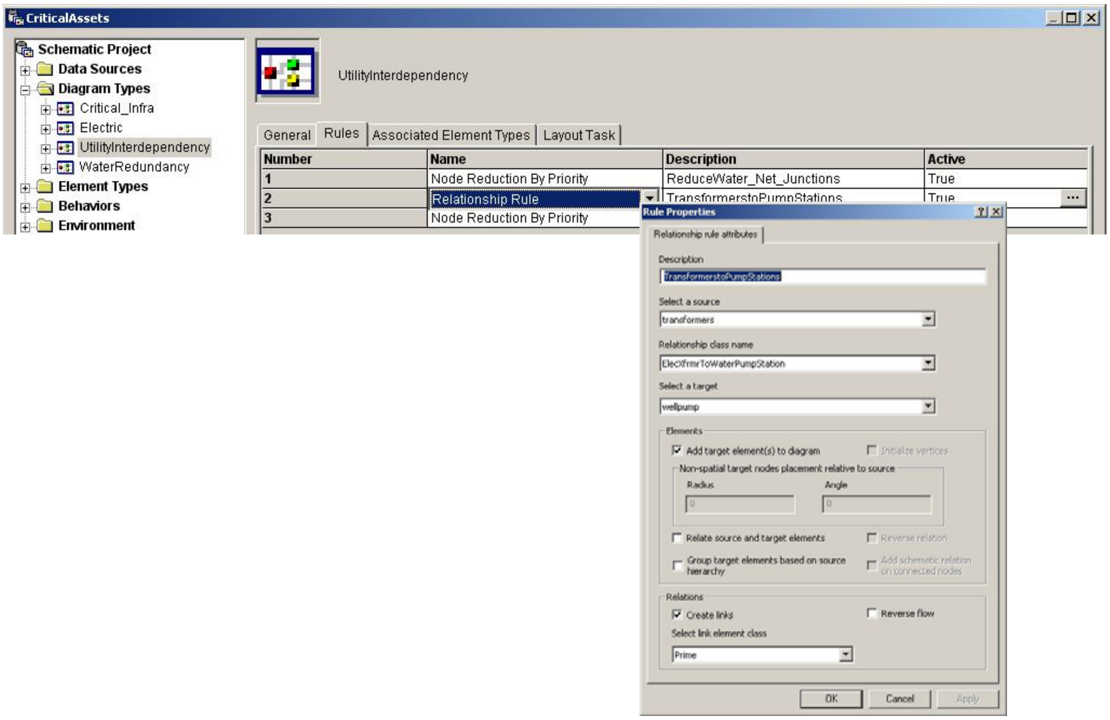
Figure 9



The loss of a circuit breaker or transformers impacts a water network, critical electric customers, and a telecom network.

Figure 10 shows how the relationship rule is set in the Schematics Designer application.

Figure 10
Relationship Rule in Designer



Connectivity in Tables

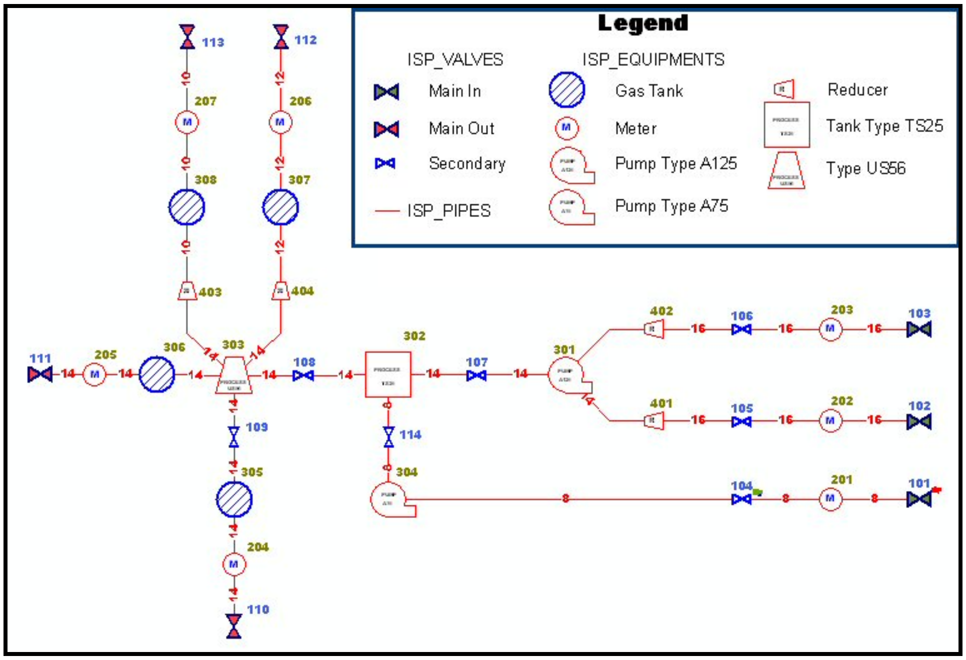
The ways connectivity is stored in tables depend largely on the kind of organization and industry. There are two main categories for storing this type of information in tables. The first is called simple. It is modeled as explicit fields, giving the connectivity between objects that are stored in other tables. The second is designated as complex because attributes must be processed to retrieve connectivity. Networks such as telecommunications or IT use complex connectivity, as they are using fiber or pair IDs to retrieve the connections between equipment. Such connectivity must be set through the Schematics Designer application using Structured Query Language (SQL) statements. In other words, the difference between simple and complex connectivity is mainly related to the simplicity or complexity of the SQL statement.

Simple Connectivity

Connectivity is simple when it is stored through explicit fields in a table that is related to a link. Two fields are needed to represent the connection from an object A to an object B. These objects can be stored in different tables and are related to nodes.

Figures 11–13 show an internal diagram of a pipeline gas plant using simple connectivity.

Figure 11
Aracaiu, Brazil, Gas Plant Diagram



Three tables are used, one for the link (ISP_PIPES) and two for the nodes (ISP_EQUIPMENTS and ISP_VALVES).

Figure 12
Link Table

ISP_PIPES : Table

OBJECTID	DIAMETER	PLACING_DATE	MAINT_DATE	FROM_NODE_NUM	TO_NODE_NUM	FCID	FOID	PLANT_NUMBER
1	14	1/14/2004	1/14/2005	305	204		6	101
2	14	1/14/2004	1/14/2005	306	205		6	101
3	12	1/14/2004	1/14/2005	307	206		6	101
4	10	1/14/2004	1/14/2005	308	207		6	101
5	18	1/14/2004	1/14/2005	115	319		1	104
6	18	1/14/2004	1/14/2005	309	322		1	104
7	12	1/14/2004	1/14/2005	116	310		1	104
8	12	1/14/2004	1/14/2005	310	323		1	104
9	12	1/14/2004	1/14/2005	311	117		1	104
10	18	1/14/2004	1/14/2005	319	309		1	104

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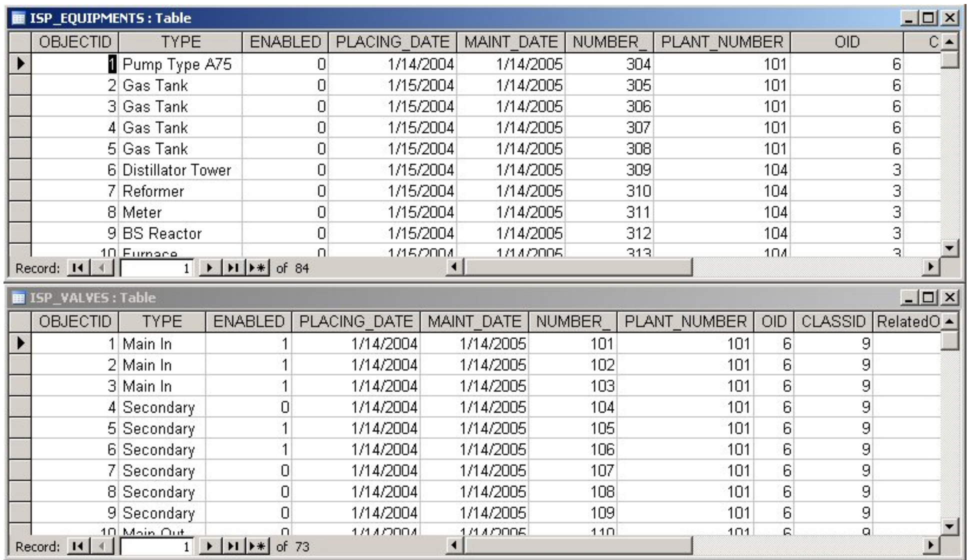
Connectivity fields are shown in light red.

Figure 13
Node Tables



ISP_EQUIPMENTS : Table

OBJECTID	TYPE	ENABLED	PLACING_DATE	MAINT_DATE	NUMBER_	PLANT_NUMBER	OID	C
1	Pump Type A75	0	1/14/2004	1/14/2005	304	101	6	
2	Gas Tank	0	1/15/2004	1/14/2005	305	101	6	
3	Gas Tank	0	1/15/2004	1/14/2005	306	101	6	
4	Gas Tank	0	1/15/2004	1/14/2005	307	101	6	
5	Gas Tank	0	1/15/2004	1/14/2005	308	101	6	
6	Distillator Tower	0	1/15/2004	1/14/2005	309	104	3	
7	Reformer	0	1/15/2004	1/14/2005	310	104	3	
8	Meter	0	1/15/2004	1/14/2005	311	104	3	
9	BS Reactor	0	1/15/2004	1/14/2005	312	104	3	
10	Furnace	0	1/15/2004	1/14/2005	313	104	3	

Record: 1 of 84

ISP_VALVES : Table

OBJECTID	TYPE	ENABLED	PLACING_DATE	MAINT_DATE	NUMBER_	PLANT_NUMBER	OID	CLASSID	RelatedO
1	Main In	1	1/14/2004	1/14/2005	101	101	6	9	
2	Main In	1	1/14/2004	1/14/2005	102	101	6	9	
3	Main In	1	1/14/2004	1/14/2005	103	101	6	9	
4	Secondary	0	1/14/2004	1/14/2005	104	101	6	9	
5	Secondary	1	1/14/2004	1/14/2005	105	101	6	9	
6	Secondary	1	1/14/2004	1/14/2005	106	101	6	9	
7	Secondary	0	1/14/2004	1/14/2005	107	101	6	9	
8	Secondary	0	1/14/2004	1/14/2005	108	101	6	9	
9	Secondary	0	1/14/2004	1/14/2005	109	101	6	9	
10	Main Out	0	1/14/2004	1/14/2005	110	101	6	9	

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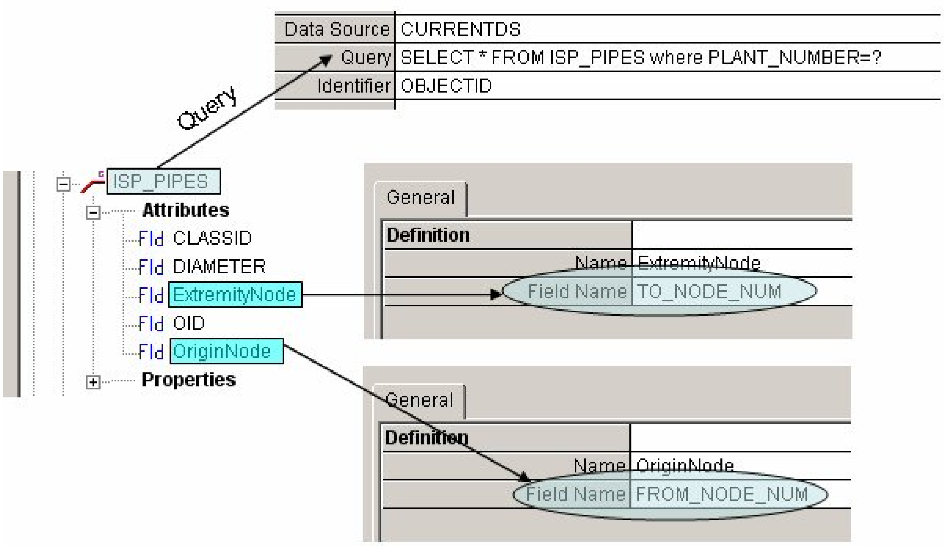
In Schematics Designer, the ISP_PIPES element type is parameterized as shown in figure 14.

Figure 14
ISP_PIPES Setting in Designer



For more information on this example or using simple connectivity, please refer to *Using ArcGIS Schematics for Inside Plant Representation* available at http://www.esri.com/software/arcgis/extensions/schematics/about/literature.html.

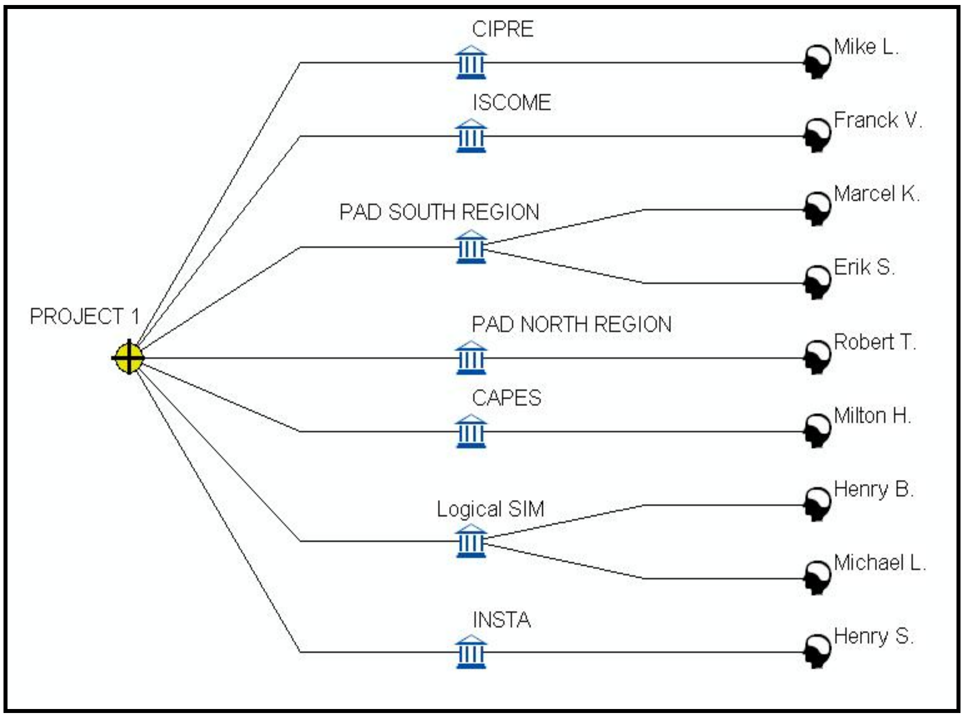
Complex Connectivity

Connectivity is complex when it is stored in tables but requires sophisticated SQL statements to retrieve or build it. This section will describe different cases and show how the related SQL statement and the Origin Node and Extremity Node attributes are set in the Schematics Designer application.

Using a Join Statement

Figures 15 and 16 are related to a project management application showing the players (companies) and company contacts that are involved in a given project.

Figure 15
Project Diagram for Project 1



The data model is very simple: it has only two tables, one for projects and one for players/contacts.

Figure 16
Tables Used to Generate Project Diagrams

Project : Table

OBJECTID	PROJECT_NAME	PLAYER_CONTACT_ID
1	PROJECT 1	1
2	PROJECT 1	14
3	PROJECT 1	20
4	PROJECT 1	25
5	PROJECT 1	32
6	PROJECT 1	33

Record: 1 of 44

Projects Table

PlayerAndContact : Table

OBJECTID	Contactperson	Player	Address
12	Gert L.	INSTA	
13	Maurice J.	INSTA	
14	Michael L.	Logical SIM	
15	Dennis V.	Logical SIM	
16	Hans W.	Logical SIM	
17	David B.	Logical SIM	

Record: 1 of 68

Players and Contacts Table

A simple query against the Project table is necessary to select the projects. This must be joined to the PlayerAndContact table to select the players, the contacts, the relationships between the projects and the players, and the relationships between the players and the contacts. Joins can be made with the explicit Join SQL keyword or implicitly as will be seen in this example. The key that is used for the join of projects and players is the PLAYER_CONTACT_ID of the Project table that relates to the OBJECTID of the PlayerAndContact table.

Figures 17 and 18 show how the parameters are set in the Schematics Designer application.

Figure 17
Player Node Parameters

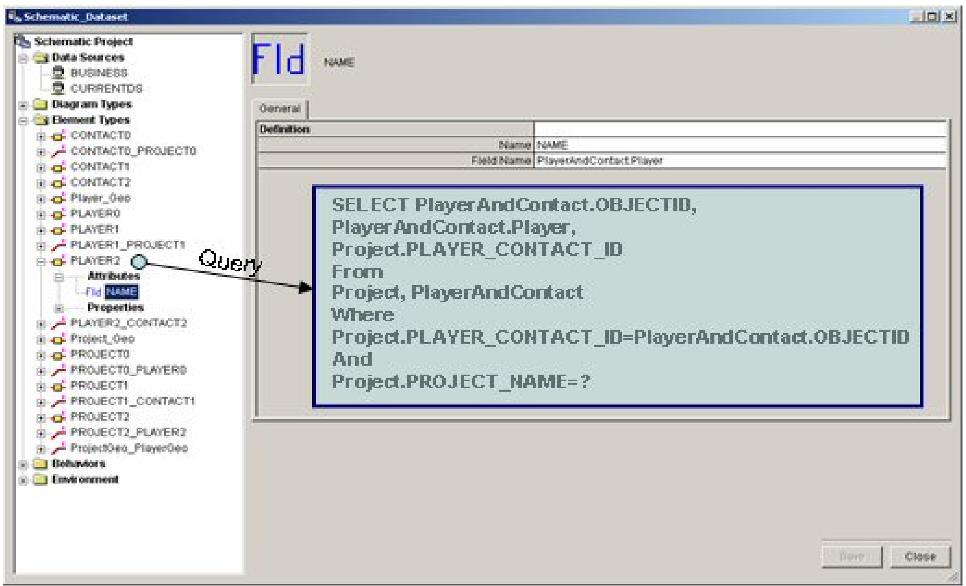
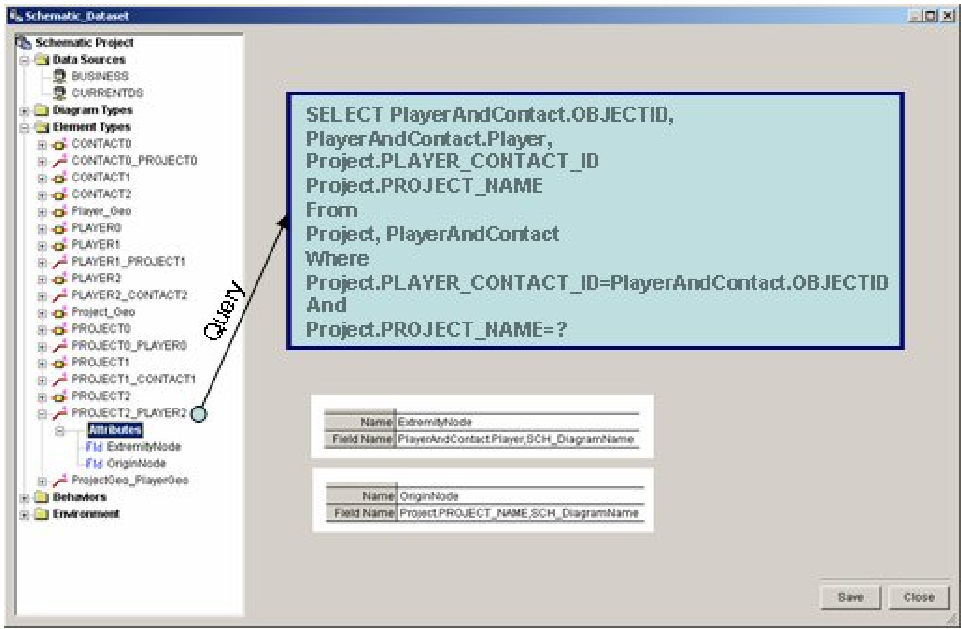


Figure 18
Project to Player Link Parameters



Using a Union Statement

Sometimes it happens that only one table is used to describe a relationship between nodes. It also describes the nodes and the links themselves. It is possible to use such a table to generate a schematic diagram that contains nodes and links.

Figures 19 and 20 show an example of the use of a Union statement.

Figure 19
Diagram Generated from One Unique Table

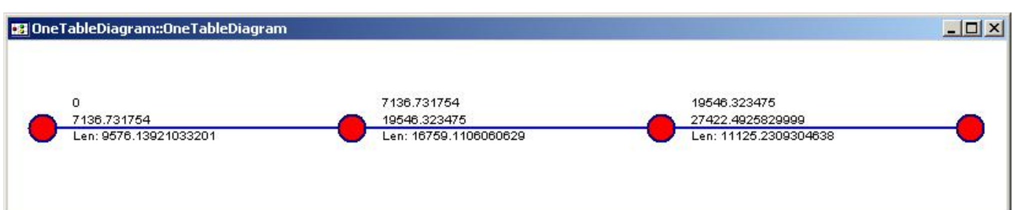


Figure 20
Unique Table

StationSeries : Table

Shape	OBJECTID	CreatedDate	EffectiveFromDate	OperationalStatus	BeginStation	EndStation
Long binary data	1	10/25/2005 12:36:07 PM	10/25/2005 12:36:07 PM	4	0	7136.731754
Long binary data	2	10/25/2005 12:36:23 PM	10/25/2005 12:36:23 PM	4	7136.731754	19546.323475
Long binary data	3	10/25/2005 12:36:44 PM	10/25/2005 12:36:44 PM	4	19546.323475	27422.4925829999

Record: 3 of 3

Figures 21 and 22 show how the parameters are set in the Schematics Designer application.

Figure 21
Node Settings in Designer

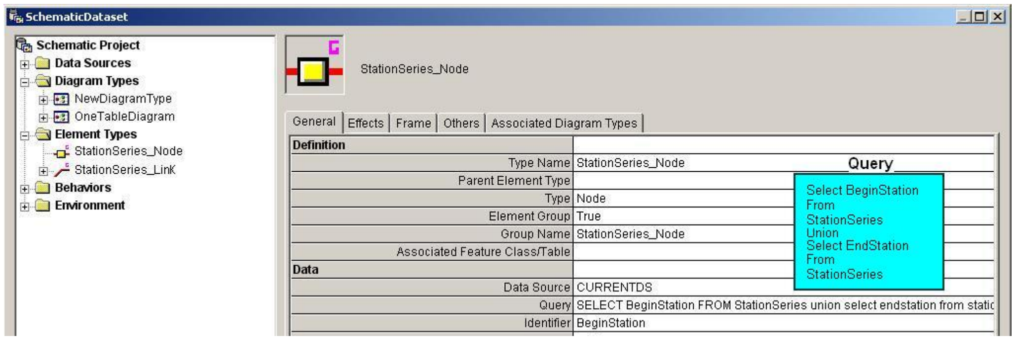
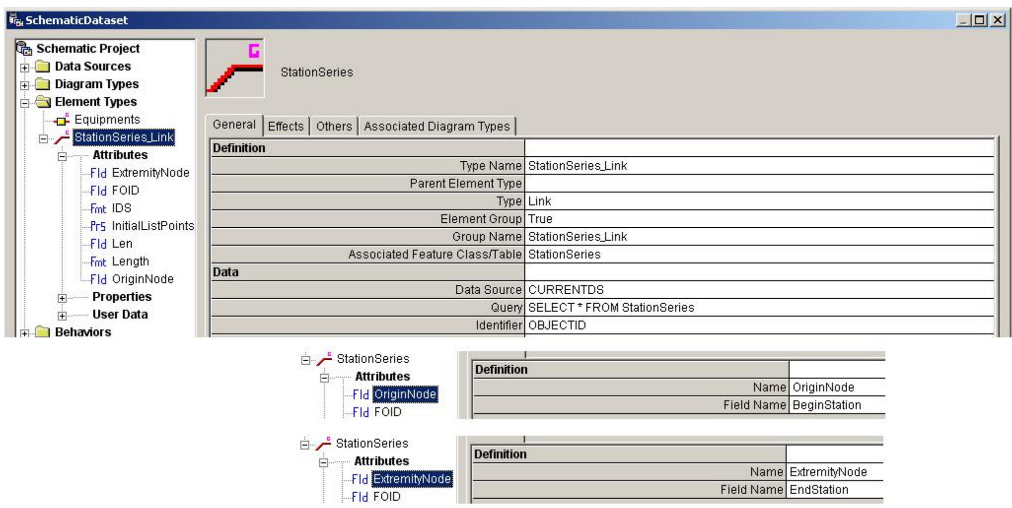


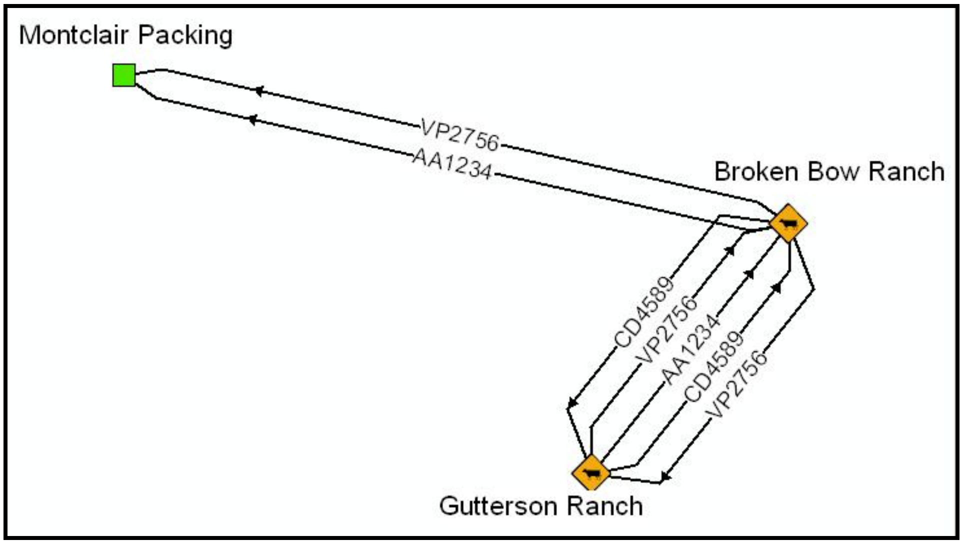
Figure 22
Link Settings in Designer



Using an In Statement

Figure 23 is related to an animal tracking application showing animal movements.

Figure 23
Premise Diagram Showing Animal Movements



Three tables were used to generate the diagram above. Two of them are feature classes (Feedlots and Ranches) while the third is just a table (Tracking). The Feedlots and Ranches tables are used to generate the nodes in the diagram while the Tracking table is used to generate the links. (See figures 24 and 25.)

Figure 24
Node Tables

Feedlots : Table

OBJECTID	SHAPE	PREMISEID	NAME	ADDRESS
1	Long binary data	100	Montclair Packing	Greeley CO
2	Long binary data	101	Garden Packing	Garden City KS
3	Long binary data	103	Rock Packing	Rock Springs WY
4	Long binary data	104	Pampacking	Pampa TX
5	Long binary data	105	Morgan Packing	Fort Morgan CO

Record: 1 of 1

Ranches : Table

OBJECTID	SHAPE	PREMISEID	NAME	ADDRESS
1	Long binary data	200	Gutterson Ranch	Fort Morgan CO
2	Long binary data	201	Hermans Ranch	Garden City KS
3	Long binary data	203	Broken Bow Ranch	Broken Bow NE
4	Long binary data	204	Horse Ranch	Rock Springs WY
5	Long binary data	205	Pampa Ranch	Pampa TX

Record: 1 of 5

Figure 25
Links Tables

Tracking : Table

OBJECTID	FromPREMISEID	ToPREMISEID	FromNAME	ToName	HERDID	DATE_Moved	COWID
1	200	203	Gutterson Ranch	Broken Bow Ranch	900	9/29/2004	AA1234
14	200	203	Gutterson Ranch	Broken Bow Ranch	950	11/6/2004	CD4589
16	203	200	Broken Bow Ranch	Gutterson Ranch	950	12/11/2004	CD4589
17	200	100	Gutterson Ranch	Monfort Packing	950	11/12/2004	CD4589
18	203	200	Broken Bow Ranch	Gutterson Ranch	900	12/24/2004	VP2756
19	200	203	Gutterson Ranch	Broken Bow Ranch	900	12/26/2004	VP2756
20	203	100	Broken Bow Ranch	Monfort Packing	900	12/27/2004	VP2756
21	100	301	Monfort Packing	Wal Mart Denver	900	12/28/2004	VP2756
64	203	100	Broken Bow Ranch	Montclair Packing	900	3/17/2005	AA1234
65	100	301	Montclair Packing	Wal Mart Denver	900	3/17/2005	AA1234

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Figures 26–28 show how the parameters are set in the Schematics Designer application.

Figure 26
Feedlots (Node) Setting in Designer

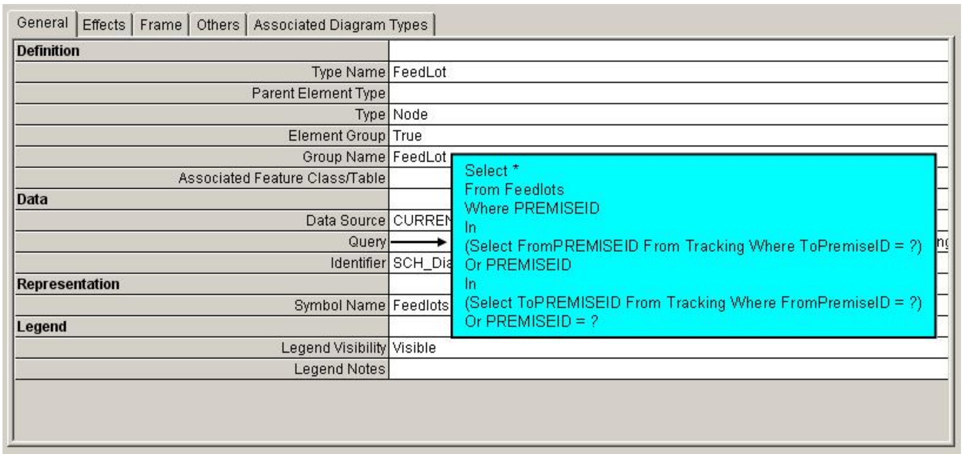

Figure 27
Ranches (Node) Setting in Designer

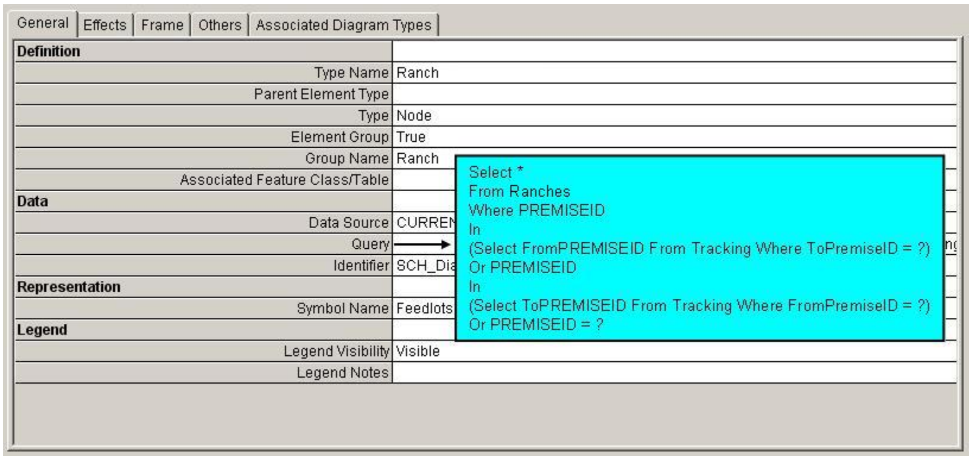

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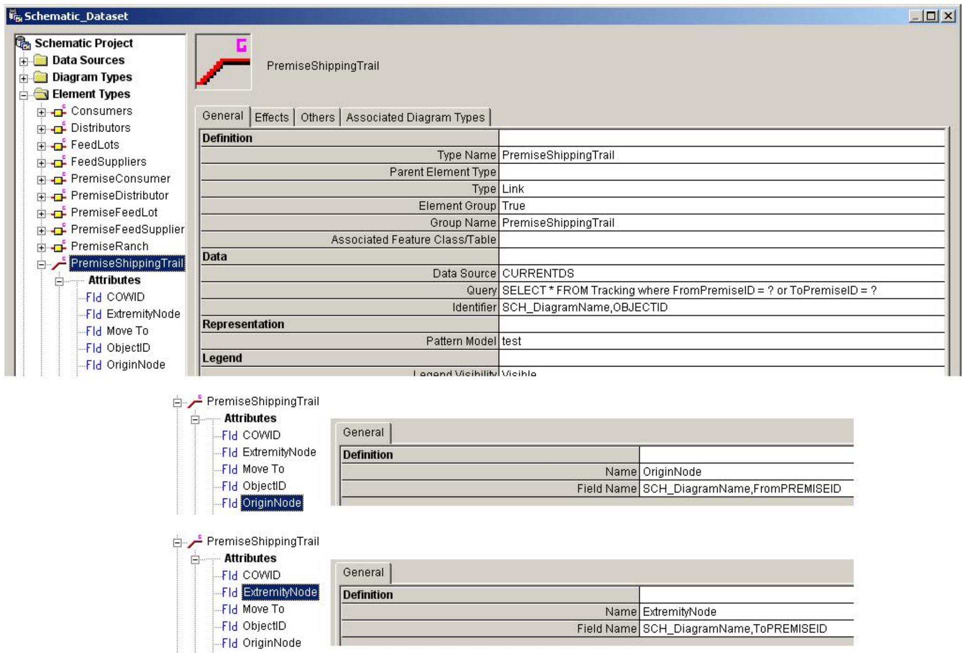
Figure 28
Tracking Link Setting in Designer



Conclusion

ArcGIS Schematics is a powerful tool to rapidly view connectivity or relationships between objects by fitting to the user data model. ArcGIS Schematics can leverage the internal connectivity of models based on geometric networks or network datasets as well as take advantage of spatial and relationship rules to handle other types of physical and logical connectivity in the model. For models not using internal connectivity, the use of SQL makes ArcGIS Schematics adaptable to any kind of connectivity and allows powerful queries to retrieve information and display it in an organized manner.

ESRI
380 New York Street
Redlands, California
92373-8100 USA

Phone: 909-793-2853
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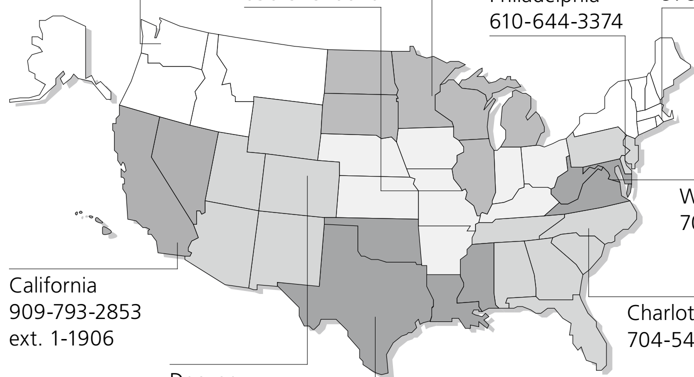

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