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A Case Study in Automated Feeder Switching Map Creation

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PRODUCT DESCRIPTION

This project's objective was to autogenerate a set of custom paper maps of distribution systems to improve switching, reliability, and customer service. The paper maps were designed as a stop-gap measure to help operators until a long-term solution with a more automated interface that can display recloser and switch loops is developed.

Results and Findings

The report presents an overview of mapping, provides several map examples, and describes how the maps are generated.

Challenges and Objective(s)

Challenges to reading and processing data to make maps include reading geographic information system (GIS) data, converting to a network format, map labeling, and graphing. The project specifically tailored the maps to be autogenerated on paper from GIS data, highlight significant points to make circuit switching easier, and allow operators to handwrite changes and updates directly on the map.

Applications, Values, and Use

The results from this project can be used to develop a more advanced map generation system that allows searching, the ability to tie into other systems, and can be updated in real time, among other features.

EPRI Perspective

The approach taken in the project had several advantages, including most of the tools were already developed for a recloser placement project; all infrastructure was based on freely available, open-source software; input data was based on shapefiles, an open file format for GIS data; and output was standard PDF format.

One of two main disadvantages is that most of the tools used to generate the maps are not commonly used in the utility industry. An alternative would be to use the programmability of the ESRI GIS system. Many of the ESRI systems support scripting, including Javascript, Python, and Visual Basic. The second disadvantage is there is no way to search, tie into other systems, and update data in real time with paper maps. Further research and development with more advanced mapping systems is expected to solve these issues.

Approach

The main steps used to create maps included importing data from GIS, extracting circuit data, identifying switching locations, reading in external data, generating a map, and converting to standard PDF format.

The sponsor utility provided their GIS data in an open format known as shapefile developed by ESRI. Most utility GIS systems can export to the shapefile format. The programming tool used to import the GIS data, process the data, and draw maps was R, an open-source processing environment based on the S language developed at Bell Laboratories

Keywords
Geographic information system (GIS)
Mapping
Circuit switching

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MAPPING PURPOSE

The goal of this project was to generate a set of custom paper maps of distribution systems to more easily perform switching to improve reliability and customer service. More specifically, the maps were designed to with the following in mind:

- For use on paper
- Highlight the significant points to make circuit switching easier (with reclosers and manually operated switches)
- Created from GIS data
- Quick turn-around time
- Autogenerated
- No need to be perfect (operators can hand write updates or changes)

The paper maps were designed to act as a stop-gap measure. The long-term solution is to have a more automated user interface that can display recloser and switch loops. The paper maps serve to help operators until that system is ready.

This project grew out of a recloser placement project. This was a semi-automated approach to identifying good candidate placements for open-tie reclosers to improve reliability. Much of the infrastructure used for mapping was already in place because it was developed for the recloser placement project (like reading circuit data from the GIS system).

Several decisions were made to make the maps more useful:

- Mainlines only (no single-phase taps) to reduce clutter
- Pole numbers given for all major reclosers and switches
- Ties to other circuits show the circuit number tied to
- Color-coded circuit sections
- Number of customers and approximate loading (at peak) given for each circuit section
- Switch type indicated by symbol
- Mainline conductor type indicated (underground cable, aerial cable, and overhead open wire)

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EXAMPLE MAPS

For each feeder, a map is generated with poles showing switches and reclosers. For each circuit that this circuit ties to, another map is generated that shows both circuits together. See Figure 2-1 for an example of one feeder with connections to two other circuits via reclosers. These reclosers have (or will have) radio control, so the dispatcher can switch them during an interruption, and the map can help the operator choose which backfeed path to use. Figure 2-2 and Figure 2-3 show feeder 506 as well as the feeder connected to it.

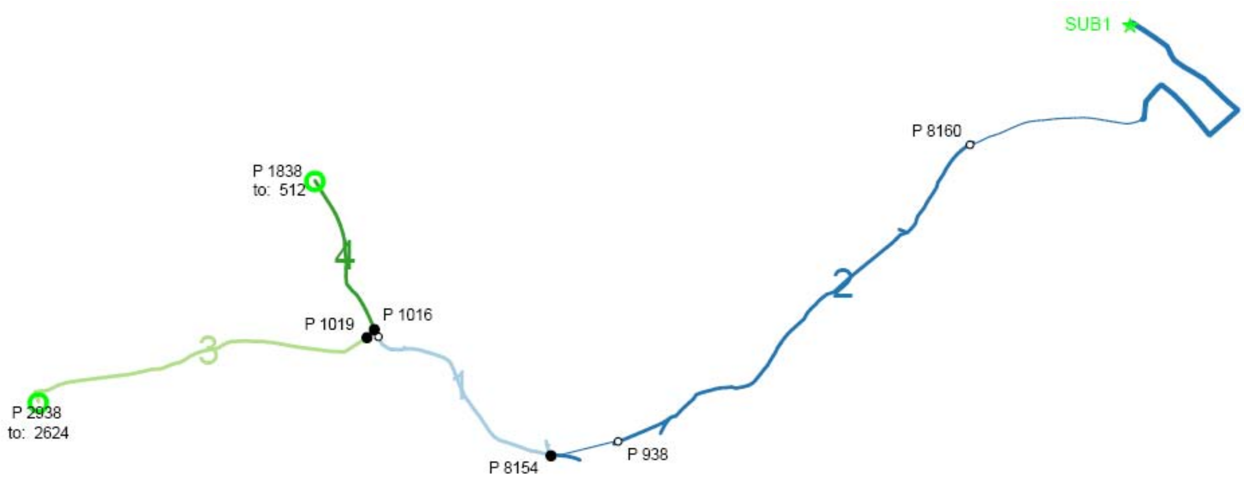


Figure 2-1
Map for Feeder 506

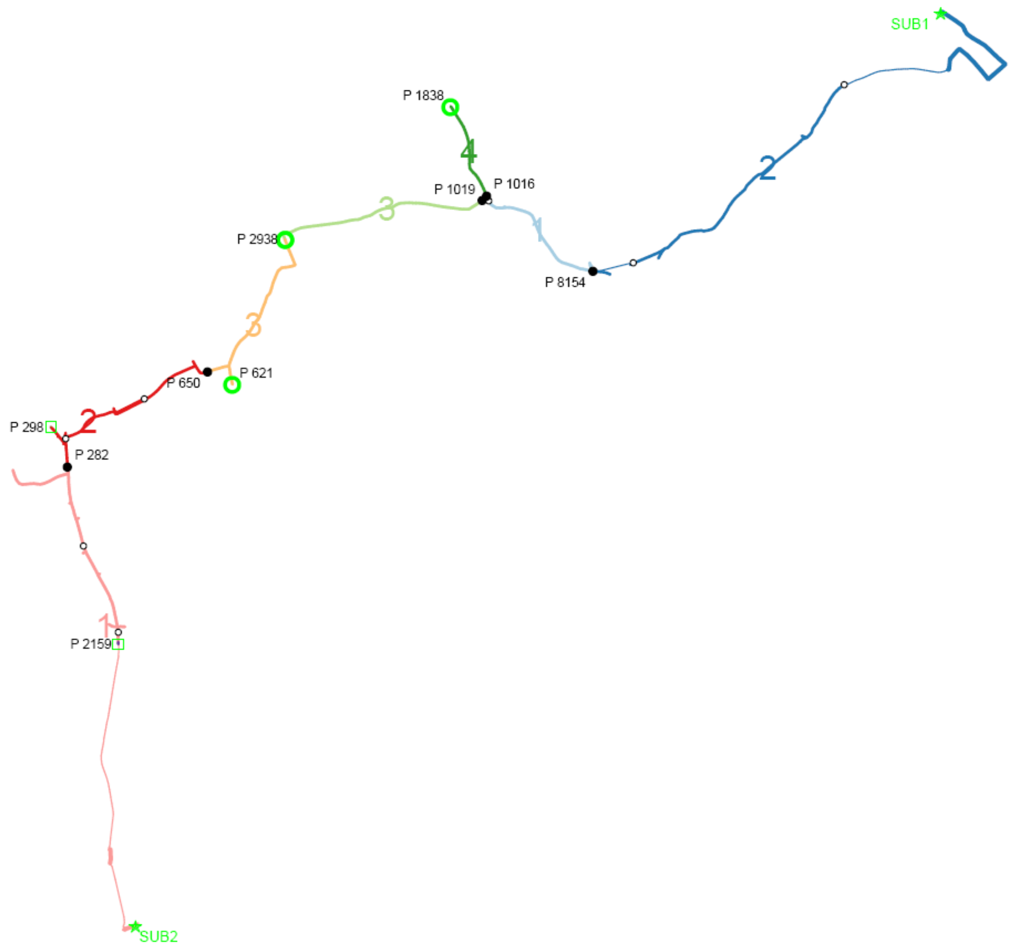


Figure 2-2
Maps for Feeder 506 Connected to 2624 at Another Substation

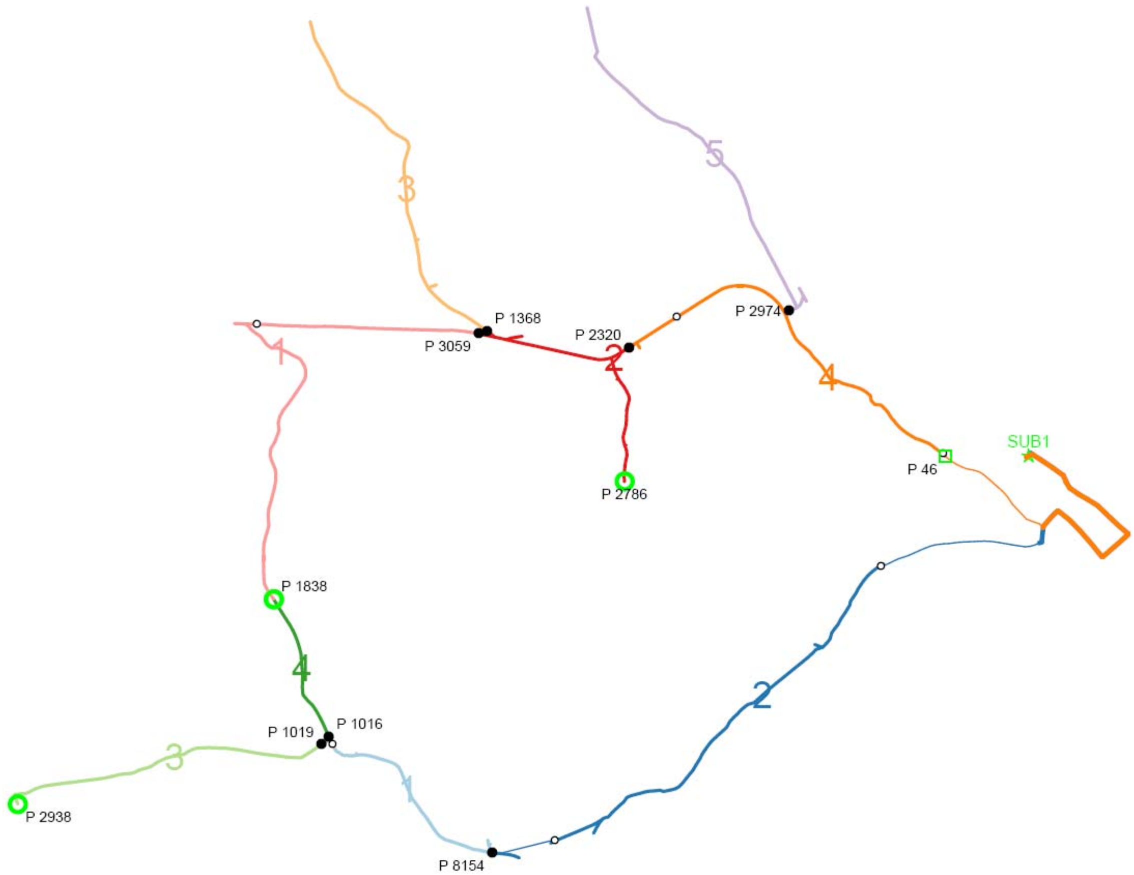
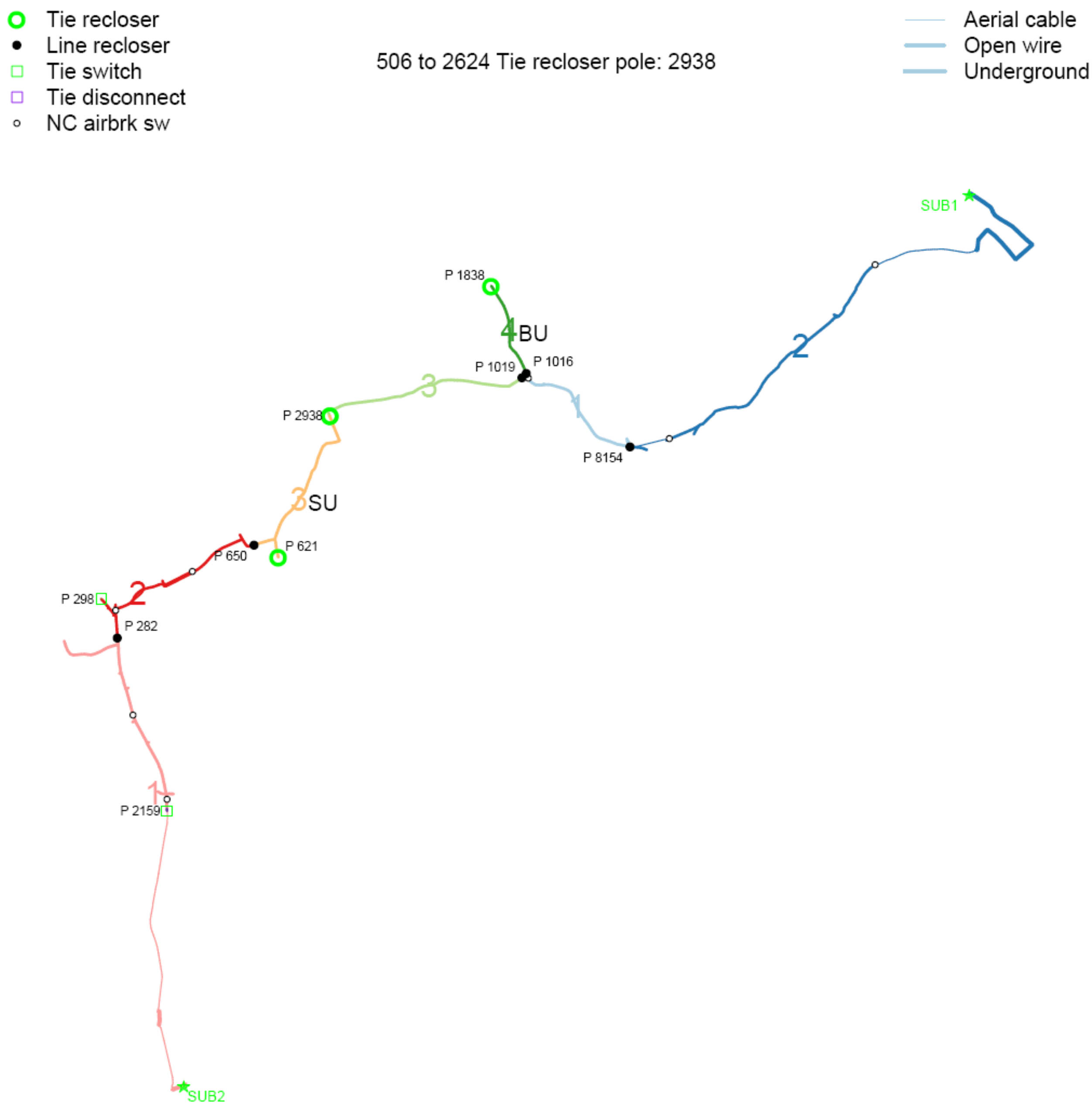


Figure 2-3
Maps for Feeder 506 Connected to 512

Figure 2-4 shows a full-page example. Features to note include:

- Title giving the circuit numbers and tie-recloser location
- Caption for the type of switch
- Caption showing line type
- Caption giving circuit ratings and a table of customers and load in amperes on each section
- Line thickness that varies by line configuration (useful for identifying station exit underground and aerial cables)



SUB2 2624 Rating=350A Emergency=410A

Section load (in amps) given the feeder load

	#Cust	100A	200A	300A	400A
1	965	47	94	140	187
2	674	34	69	103	137
3	397	17	34	51	68

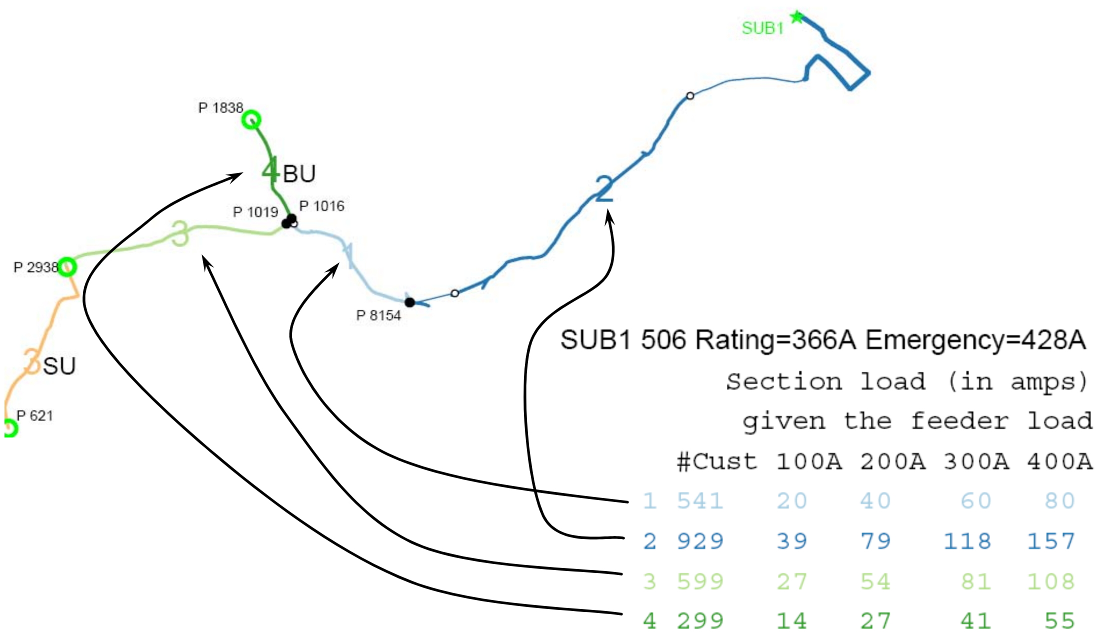
SUB1 506 Rating=366A Emergency=428A

Section load (in amps) given the feeder load

	#Cust	100A	200A	300A	400A
1	541	20	40	60	80
2	929	39	79	118	157
3	599	27	54	81	108
4	299	14	27	41	55

Figure 2-4
Complete Page Representation

Figure 2-5 shows how the loading table relates to the section. It is color coded and indicated by a section number. The loads were allocated by connected transformer kVA. The table is given based on a feeder loading of 100, 200, 300, and 400 A. That way, an operator can look up the circuit load and estimate the section load from the table. For example, for a feeder load of about 350 A, the operator could see that the load on that section is about 95 A (interpolating between 81 A and 108 A based on the fact that the 350 A is halfway between the table headings of 300 and 400 A.



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3	599	27	54	81	108
4	299	14	27	41	55

Figure 2-5
Table Showing Customers and Load by Section

3
MAP GENERATION

The main steps used to create maps included:

- Import data from GIS
- Extract circuit data and reduce it
- Identify switching locations
- Read in external data, including circuit loadings
- Generate a map, including color coding and feature labeling
- Convert to standard PDF format

The sponsor utility provided its GIS data in shapefile format.[1] Shapefiles are based on an open format developed by ESRI (www.esri.com). The host utility uses ArcView to interface to their GIS database. ArcView can export to shapefiles. Most utility GIS systems can export to the shapefile format.

The programming tool used to import the GIS data, process the data, and draw maps was *R*, an open-source data analysis package (www.r-project.org). R is a processing environment based on the S language developed at Bell Laboratories by John Chambers and colleagues.i[2] R's strengths are graphics, data analysis, and flexibility. R offers advanced types of graphs, extreme flexibility, and precise, good-looking results. R offers sophisticated file-manipulation capabilities, access to external databases, and many data-processing and statistical functions. The S language itself is very flexible, powerful, and extendible. R is an interpreted computer language with extensive support for statistical and engineering calculations. In many ways, the R system is similar to Matlab. Over 1700 add-on packages are available (cran.r-project.org). Several of these add-ons support analysis and processing of mapping and other GIS data.

Several of the steps to reading data and processing it to make maps included:

- Reading GIS data – The *maptools* package by Roger Bivand was used to read shapefiles into R.[3]
- Converting to a network format – GIS data in shapefile format has no concept of a network, that lines and cables and switches are tied together. It just has segments and nodes. The *spdep* package provided routines to help convert the circuit segments into an interconnected

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1 Environmental Systems Research Institute, Inc. (July, 1998). ESRI Shapefile technical description. http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf.

2 R. Ihaka and R. Gentleman, "R: A language for data analysis and graphics," Journal of Computational and Graphical Statistics, vol. 5, pp. 299-314, 1996.

3 http://cran.r-project.org/web/packages/maptools/index.html.

network representation.[4] It also allows splitting networks, that was especially important to break each switching section at each recloser or switch.

- Map labeling – Automated labeling of maps is a detailed science. Moving labels to avoid overlaps helps with map readability. The point labeling algorithm used for labeling switches and other nodes was based on an optimization based on simulated annealing.[5] The code used for this is now part of the maptools package (pointLabel).
- Graphing – R has very good built-in drawing and graphing capabilities that supports PDF output, making it easy to generate the maps as desired.

Because of the readily available add-on packages for R, the code to generate the custom maps was less than 900 lines of code. Further advantages of this approach to custom map processing include:

- Most of the tools were already developed for another project.
- All infrastructure was based on freely available, open-source software.
- The infrastructure used provided most of what was needed to read inputs and generate the maps, so the programming effort was manageable.
- We had very fine-grain control of the entire conversion and output process, so we could customize it easily.
- Input data was based on shapefiles, an open file format for GIS data.
- Output was standard PDF format.

Disadvantages of this approach include:

- Most of the tools used to generate the maps are not commonly used in the utility industry.
- Paper has limitations: no searching, no way to tie to other systems, can't be updated in real time.

Another approach that could work well here is to use the programmability of the ESRI GIS system itself. Many of the ESRI systems and versions can support scripting, including Javascript, Python, and Visual Basic. Visual Basic is the most commonly used scripting system used in the ESRI products.

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[4] http://cran.r-project.org/web/packages/spdep/index.html

[5] Jon Christensen, Joe Marks, and Stuart Shieber. Placing text labels on maps and diagrams. Paul Heckbert, editor, Graphics Gems IV, pages 497-504. Academic Press, Boston, MA, 1994. http://www.eecs.harvard.edu/~shieber/Biblio/Papers/jc.label.pdf

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