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Automating last-mile power connection discovery in datacenters

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ABSTRACT

Up-to-date records of last mile power connection information in a datacenter are useful, e.g., to enable data center engineers to reason about the power-network dependency of machines; to monitor aggregate power consumed by a group of machines; etc. Such records are typically obtained manually, e.g., by associating barcodes with both distribution equipment (junction boxes) and power loads (racks) and scanning the barcodes to establish distribution-to-load mapping. The present manual methods of power-connection discovery are labor-intensive.

This disclosure describes automated discovery of last-mile power connection information in a datacenter. Power cables (whips) that connect racks to junction boxes are made available in several colors and possibly barcoded. Each whip has length less than a certain maximum. A robot moves down the aisles of a datacenter capturing images of racks, whips, junction boxes, and their barcodes. An image-processing engine maps a rack to a junction box by identifying a whip of common color (or barcode) attached to both rack and junction box. The limited length of the whip is used to disambiguate distribution-to-load connections.

KEYWORDS

- datacenter
- power network
- power connection topology
- robotic process automation
- robotic data collection

BACKGROUND

Maintaining up to date records of last mile power connection information in a datacenter is useful for a variety of reasons. For example, up to date records enable data center engineers to reason about compute, network and storage resources that will potentially lose power if a certain power equipment is taken down for maintenance or replacement. Additionally, accurate recordkeeping enables monitoring of the aggregate power load presented by a specific group of machines, network devices, etc. This information can be used to infer, for example, whether a given set of machines has adequate power available to it.

In its most basic form, such recordkeeping can be done by manually identifying last-mile distribution equipment and the power loads that they connect to. In a slightly more automated form, barcodes can be associated with both the distribution equipment and some groupings of power loads (e.g., a rack). Barcode scanners are used to manually record the names of the entities involved in the connection, which information is persisted in a highly available database. However, this scheme too is labor intensive; scanning twice for each rack in the fleet is time consuming. Since rack positions and power connections change periodically, it is necessary to perform periodic audits of rack connection information.

Datacenter Layout and Power Connections

Datacenters contain machines and networking equipment organized into racks. Racks typically consume AC power and convert it to DC power using rectifiers placed within the rack. Machines and networking devices consume DC power to perform their tasks.

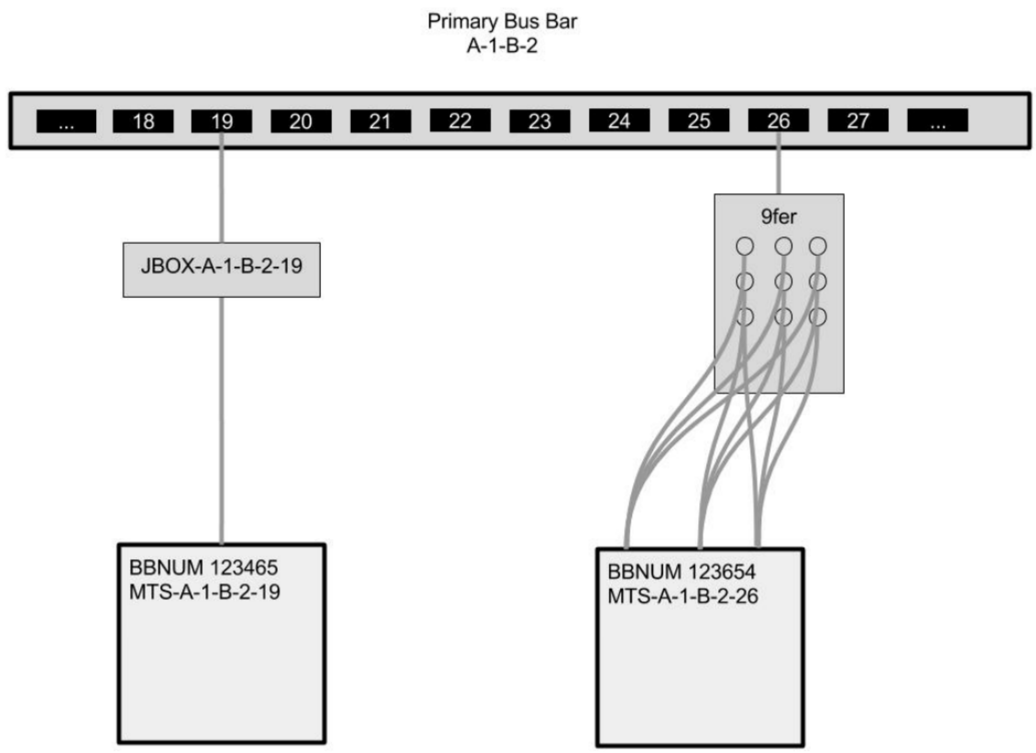

Fig. 1: Bus connection hierarchy

AC power is typically delivered to a rack using a cable known as a whip. Whips connect bus tap-off devices such as junction boxes (JBOX) and 9-fers (a junction box with nine outlets), etc. Junction boxes and racks typically have unique identifiers. In Fig. 1, JBOX-A-1-B-2-19 is a named junction box. BBNUM 123465 is a rack. The cable between them is a whip. Similarly, a 9-fer supplies power to a rack named BBNUM 123654.

Junction boxes are typically powered by bus bars, which usually run linearly within the datacenter. In Fig. 1, the JBOX and the 9-fer draw power from primary bus bar A1-B-2. Racks are organized linearly under bus bars for ease of power connection. Tens, sometimes hundreds, of rows of racks are typically seen on a modern datacenter floor, with an aggregate number of rack-spots numbering in the hundreds or thousands. Each rack spot implies at least one power connection between a bus tap-off device and a rack. There are thus several last-mile power connections to track in a typical data center.

DESCRIPTION

This disclosure automates discovery of power-connection topology by using mobile, camera-equipped robots in conjunction with a power connection disambiguation scheme. Rack power connection information is automatically recorded, periodically audited, analyzed, and stored. The resulting information can be used both within the datacenter as well as in other power tracking systems.

Robot navigation

To minimize costs, the robots navigate by guide rails (optionally electrified) some distance above the racks, by line-markers on the floor for wheeled robots to follow, or by a sensor-based navigation system. Any mobile robotic system can be utilized. Some robotic systems may perform simultaneous localization and mapping (SLAM). To minimize human intervention, a robot is able to autonomously navigate to any rack spot on the datacenter floor or to any spot for which power connection information is to be recorded. The navigation system may optionally encode finer grain location information to help the robot calibrate its position within the datacenter. While any of the options will work, rails have the advantage of having a more direct view of rack power connections, since these connections tend to be closer to the top of the rack. For simplicity, the figures that follow show a mobile robot without rails.

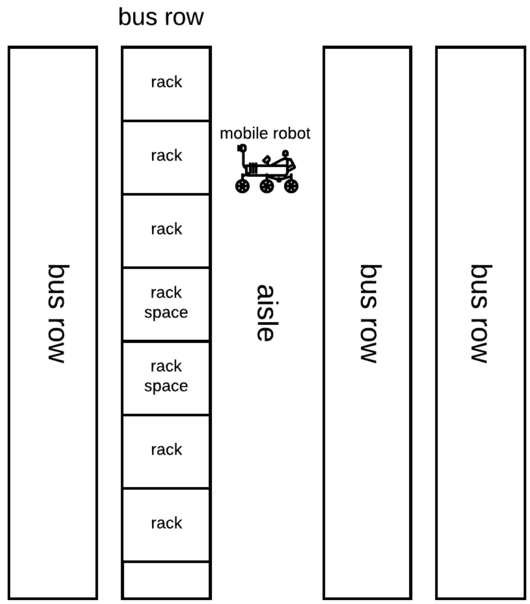

Fig. 2A: Robot scanning (top view)

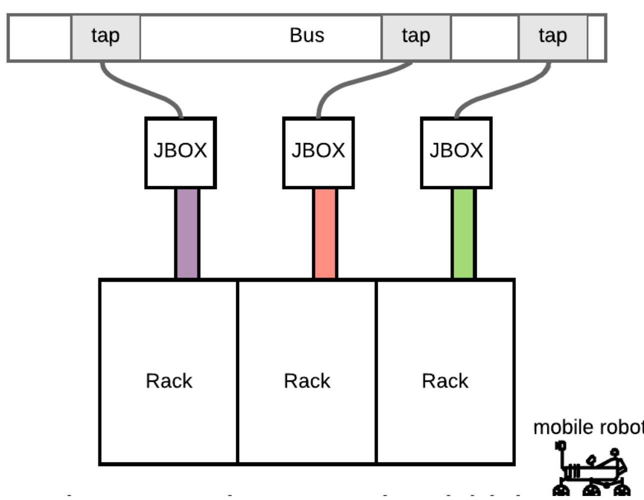

Fig. 2B: Robot scanning (side view)

A scheduling service directs the robot to racks in need of scanning. The scheduling service decides when a robot is to be powered on and placed at the starting point of a scan grid, what sections of the grid are to be recorded, etc.

The scheduling service monitors databases that record the build state of racks. Upon determining that racks that have recently appeared in one part of the datacenter, the scheduling service creates a scan schedule to cover those racks. The scheduling service also monitors racks that haven't been scanned or audited within the past *N* days, where *N* is a configurable parameter. The scheduling service creates plans for periodically auditing co-located racks with relatively stale power connection scans.

Data capture and analysis

Digital images of the datacenter racks, power whips, and junction boxes are collected by a digital camera module mounted atop the robot. Multiple images of each rack, power whip, and junction box are obtained from multiple angles, allowing approximate 3D reconstruction of each row of racks in the datacenter environment.

These images are sent to a software processing pipeline along with timestamps and precise locations in the datacenter. The locations at which the images were taken are supplied by physical location markers or software-based location tags. After receiving a series of images corresponding to one side of a row of racks in the datacenter, the software pipeline identifies racks, power whips, and junction boxes, as described below.

Rack serial number barcodes are identified from 2D images and verified against a pre-existing database of rack serial numbers. Similarly, power junction box barcode labels are identified from 2D images and verified against a database of junction box identifiers. Power whips are categorized in the 2D images by color (Fig. 3), barcode, or both (Fig. 4), but are not verified against a database because their barcodes are not necessarily unique.

For identified and validated barcodes, the software pipeline correlates the positions within the datacenter at which the images were taken with precise rack location planning information. The rack location information is typically known to high accuracy, e.g., 1 mm. This correlation enables the software pipeline to map the 2D images to the known spatial extent of each rack and thus, enables identification of rack boundaries in images.

The rack boundaries are searched for whip connections, identified by color. This process is of limited complexity due to the restricted set of allowable whip colors. The outcome of this step is a mapping between rack identifiers and whip colors.

The software pipeline performs a similar identification of junction box locations in planning data, correlation of planning data and image sensor location, mapping of images to known junction boxes, and identification of connections between junction boxes and whips by color.

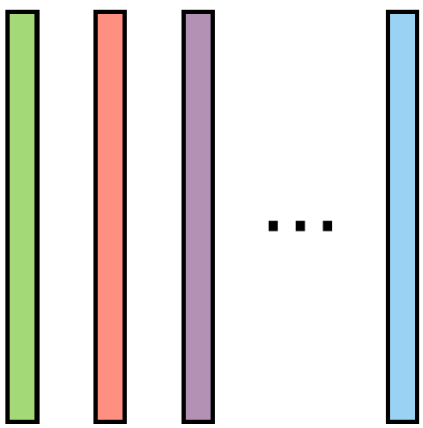

Fig. 3: Colored power whips in several colors

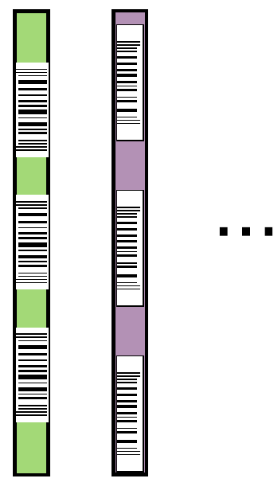

Fig. 4: Colored and barcoded cables in one or more colors

<u>Associating racks to junction boxes</u>

Racks are associated to junction boxes by whip color and spatial proximity. Per techniques of this disclosure, no two neighboring junction boxes share a whip color/barcode combination and whips are of a known maximum length. Therefore, the software pipeline only considers potential rack/junction box associations within a fixed spatial radius, *R*. For each identified rack, the pipeline identifies junction boxes within a radius *R* of the rack boundary that share a whip color/barcode combination with the rack. Individual racks can have multiple power connections, but a junction box has only one whip. The software pipeline identifies the appropriate number of power connections for the rack from a database of rack types and serial numbers. If the number of matched junction boxes within radius *R* matches the number of planned power connections, the rack under consideration is marked as complete and the power connections are recorded in a power connection database. If the number of matched junction boxes differs from the planned number of power connections for the rack, the rack is selected for manual verification.

Although described for datacenters, the techniques of this disclosure are useful wherever there is a need to track power connection topology between a large set of power consumers and power supplies in a localized area. Datacenters present many such opportunities since machines are placed into homogenized entities (racks), which are powered by bus bars and tap-off boxes. A similar situation exists in refineries, factory floors, etc.

CONCLUSION

This disclosure describes automated discovery of last-mile power connection information in a datacenter. Power cables (whips) that connect racks to junction boxes are made available in several colors and possibly barcoded. Each whip has length less than a certain maximum. A robot moves down the aisles of a datacenter capturing images of racks, whips, junction boxes, and their barcodes. An image-processing engine maps a rack to a junction box by identifying a whip of common color (or barcode) attached to both rack and junction box. The limited length of the whip is used to disambiguate junction-box-to-rack connections.