Lessons in Systems Thinking

Margaret Holzmann



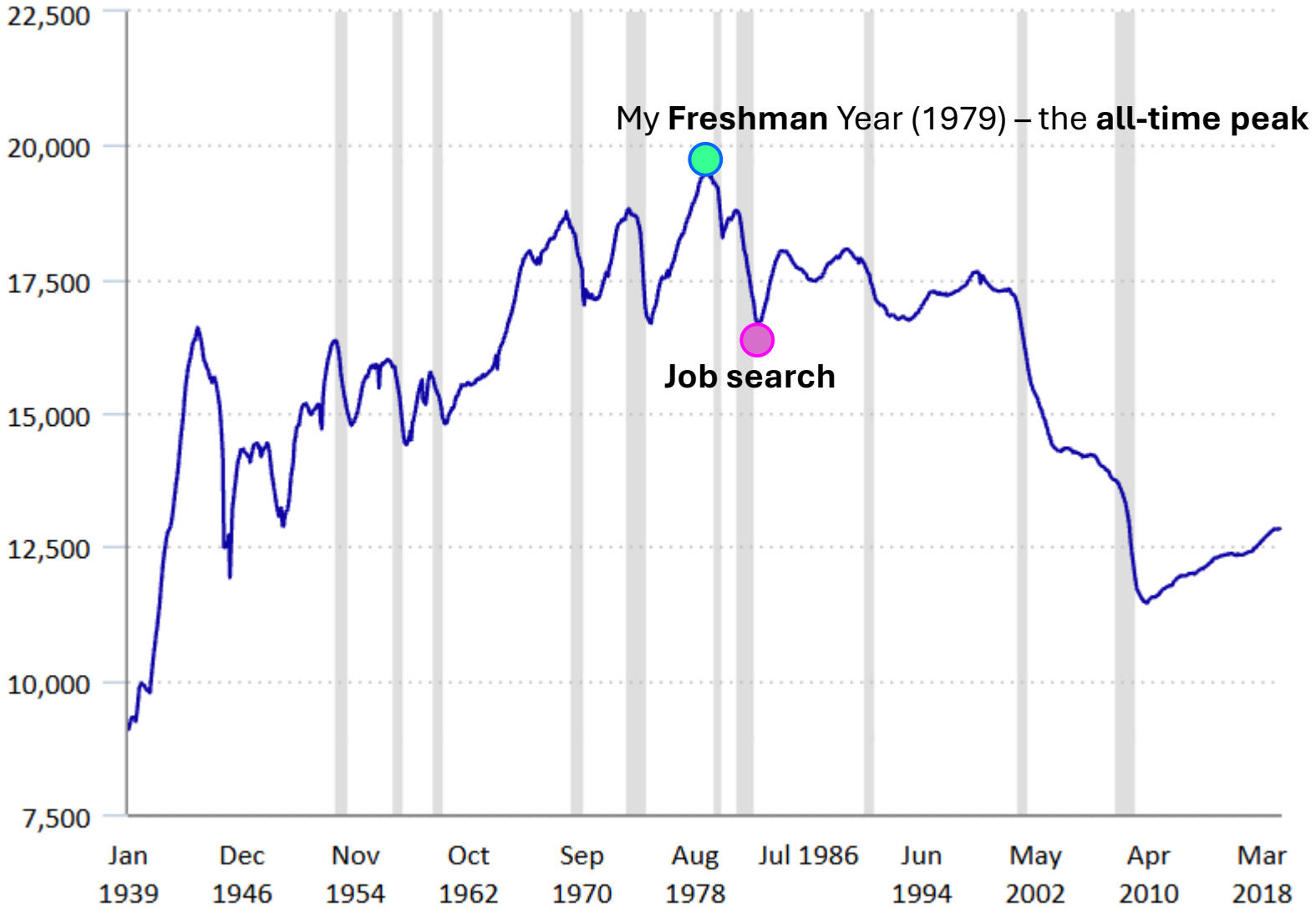
Murray Russell Smith

- My Dad
- Raised on a farm in Wyoming, Ontario, Canada
- 40+ years at Ford Motor Company, Dearborn Michigan, as a Purchasing Specialist

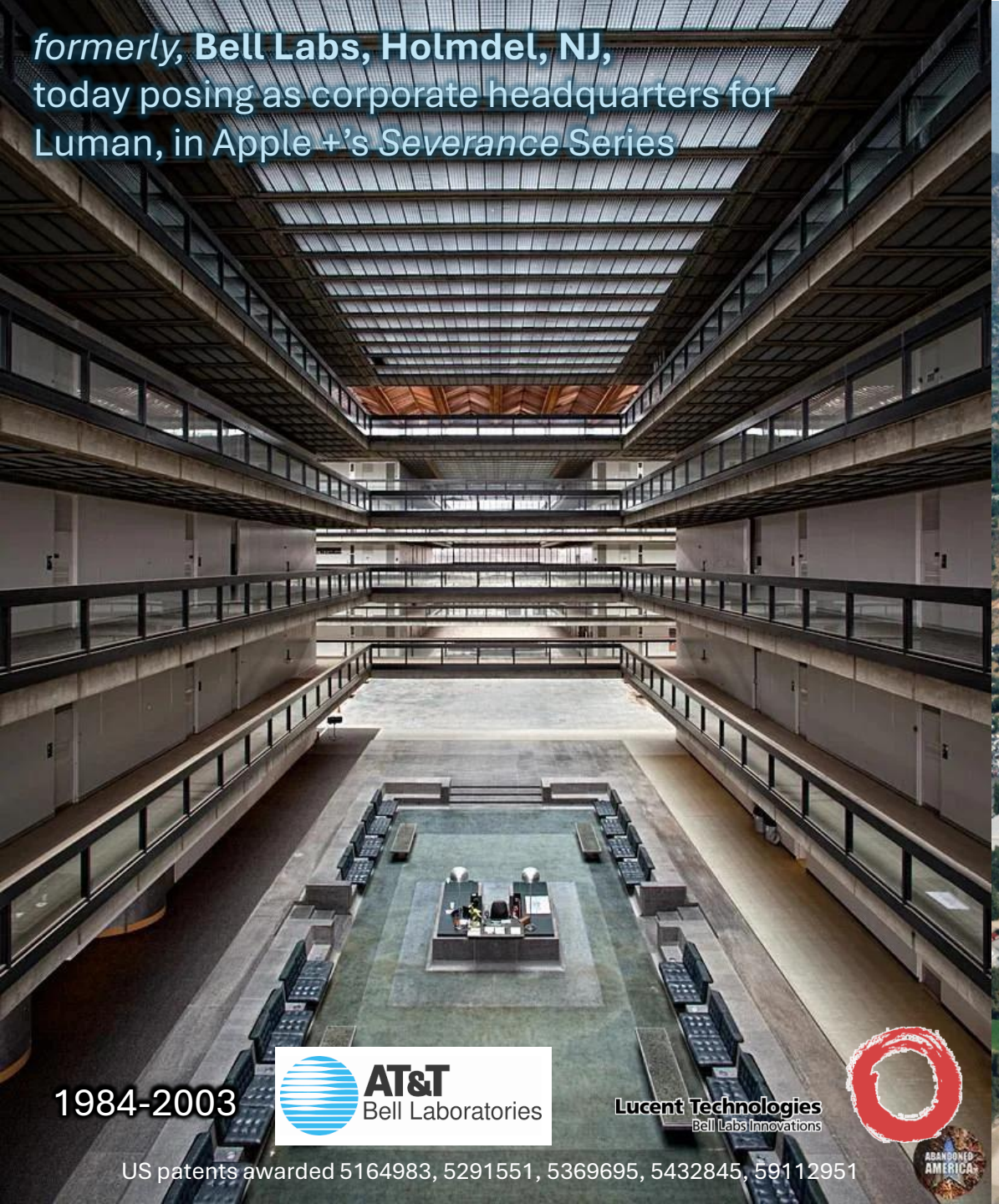


Decision-omics

Employment in **Manufacturing**, January 1939 – June 2019, seasonally



Bureau of Labor Statistics-"Beyond the Numbers: Forty Years of Falling Manufacturing Employment" Nov 2020, Vol. 9/No. 16


formerly, **Bell Labs, Holmdel, NJ,**
today posing as corporate headquarters for
Luman, in Apple +'s *Severance* Series
1984-2003
AT&T
Bell Laboratories
Lucent Technologies
Bell Labs Innovations
US patents awarded 5164983, 5291551, 5369695, 5432845, 59112951

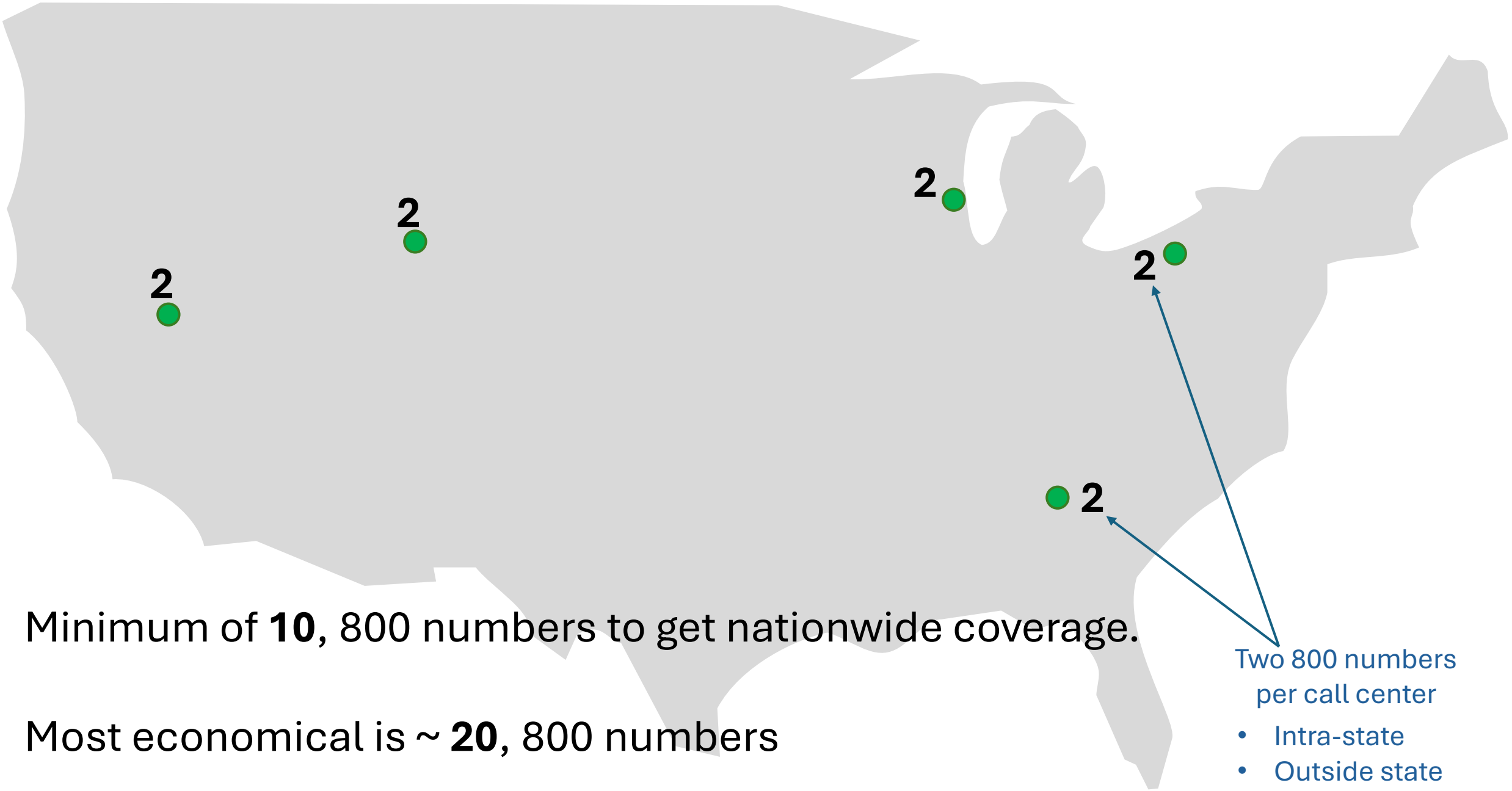

Pasadena, CA
2003-2017
NASA
Jet Propulsion Laboratory
California Institute of Technology

The Knitwit

Evolution of Architecture of “Toll-free” Calling

- A phone call was expensive - depended on distance and call length.
- 1930’s – 1967: Operator-Assisted Collect (reverse-charge) call
- 1967: In-bound WATS (Wide Area Telephone Service) called fondly, “800” service
  - AT&T had reserved area codes with “0” for future, special services.
  - 800-NXX-XXXX – the NXX specified the caller’s geographical region (not the called’s).
    - Implemented by hard-wiring trunks.
    - Trunks aggregate voice & data traffic between switches in a telephone network.

JC Penney Catalog Order Centers, **leading up to1981**



Minimum of **10**, 800 numbers to get nationwide coverage.

Most economical is ~ **20**, 800 numbers

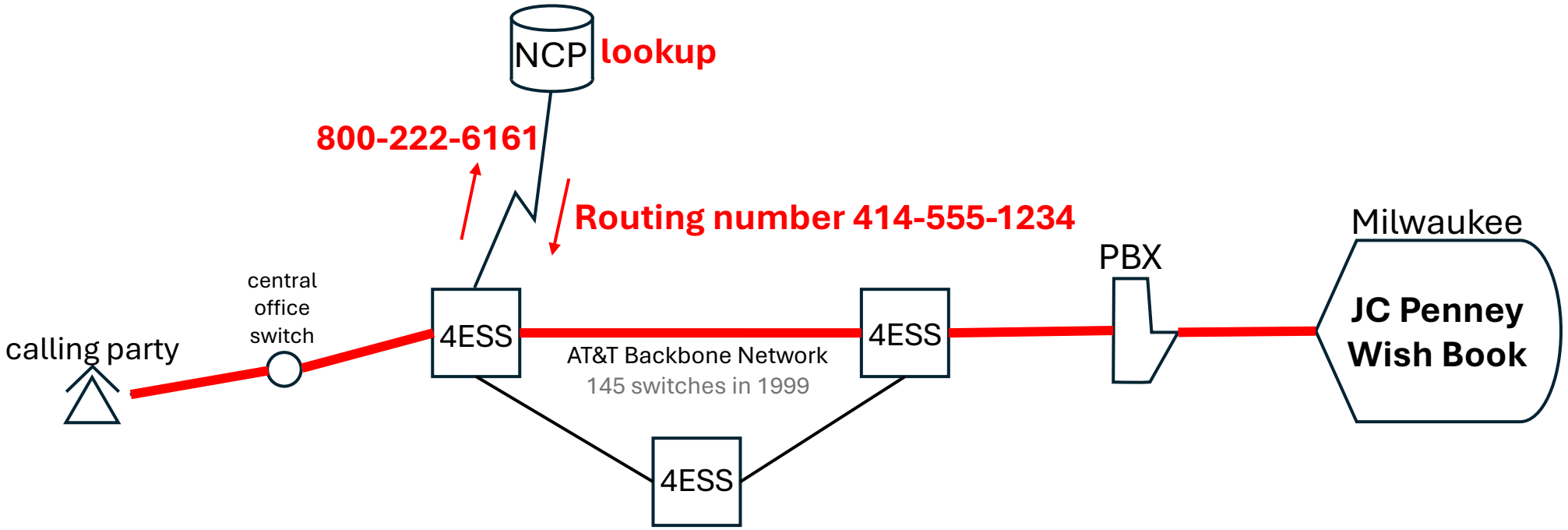
Evolution of Architecture of “Toll-free” Calling

Nationwide single-number 800 Service

- In 1981 – convert an 800 number into a physical *routing number* (area code + exchange + line).
  - *Originating Switch* queries a database (Network Control Point) via signaling network (circa 1975).
  - Additional routing features were quickly added.
  - Rob Weber, a systems engineer, came up with this idea.

- All features fine-tuned the initial routing.

800 Service Architecture, 1980's

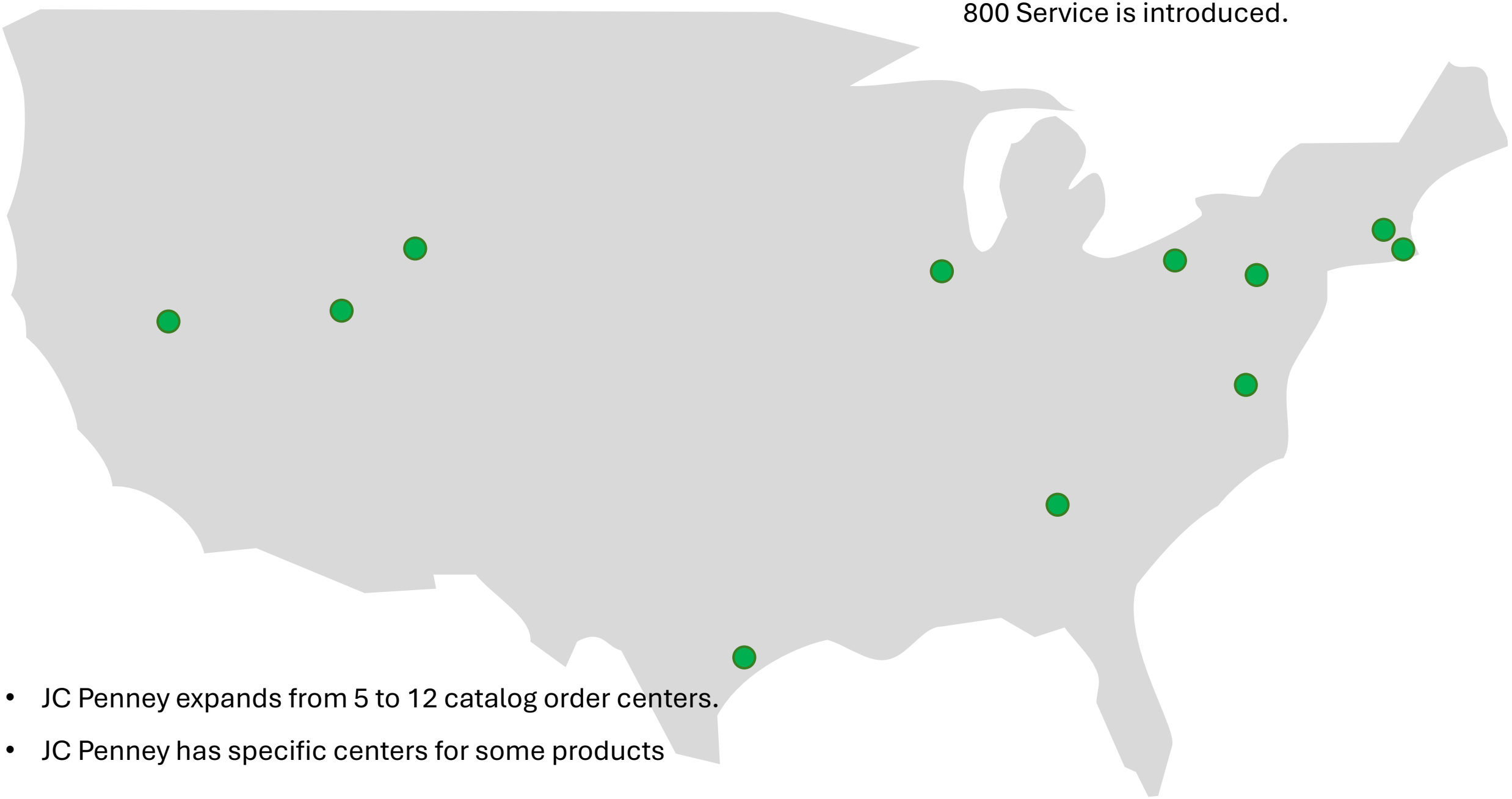


Private Branch Exchange (PBX) – call distribution,
And management at the AT&T customer's site

#4 Electronic Switching System (4ESS) –
introduced in 1970, retired in 2007

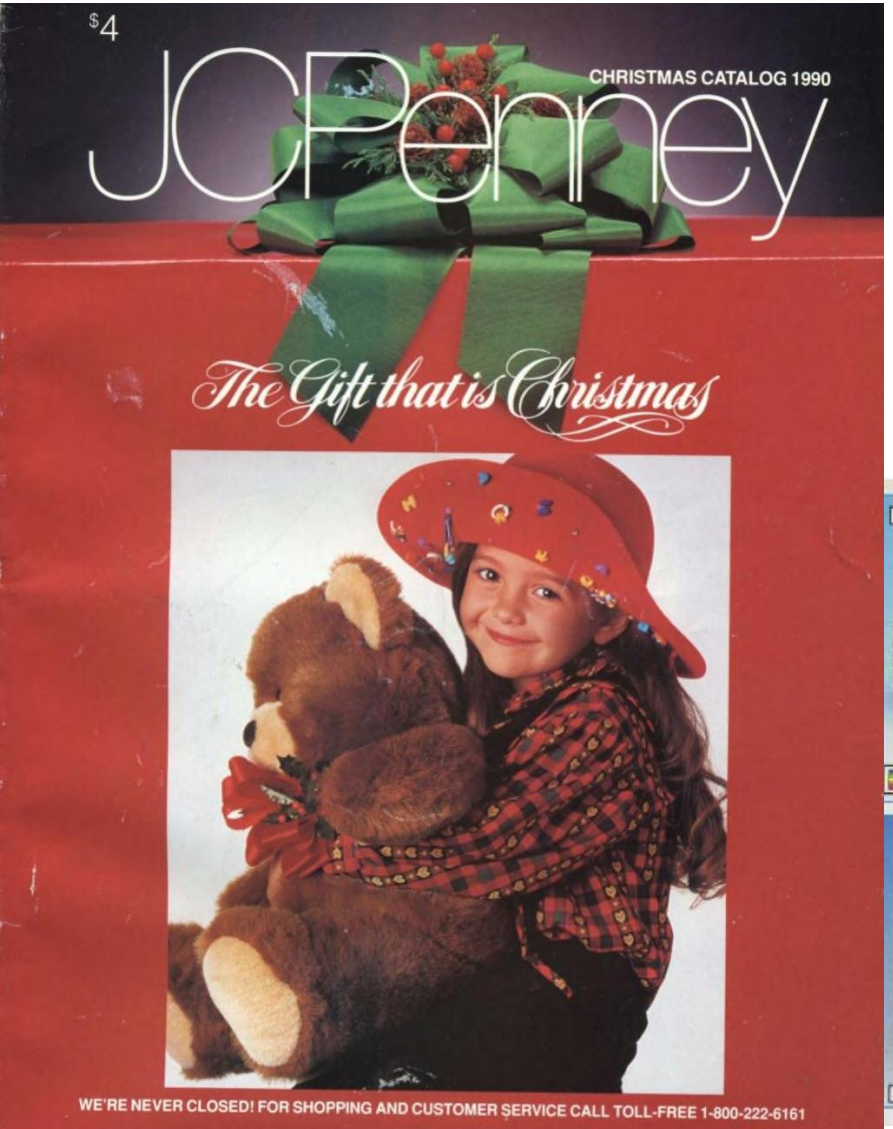
Network Control Point (NCP) –
Introduced in 1975 as local database lookup
Networked in 1980

JC Penney Catalog Order Centers, **1991** - five years after single-number 800 Service is introduced.

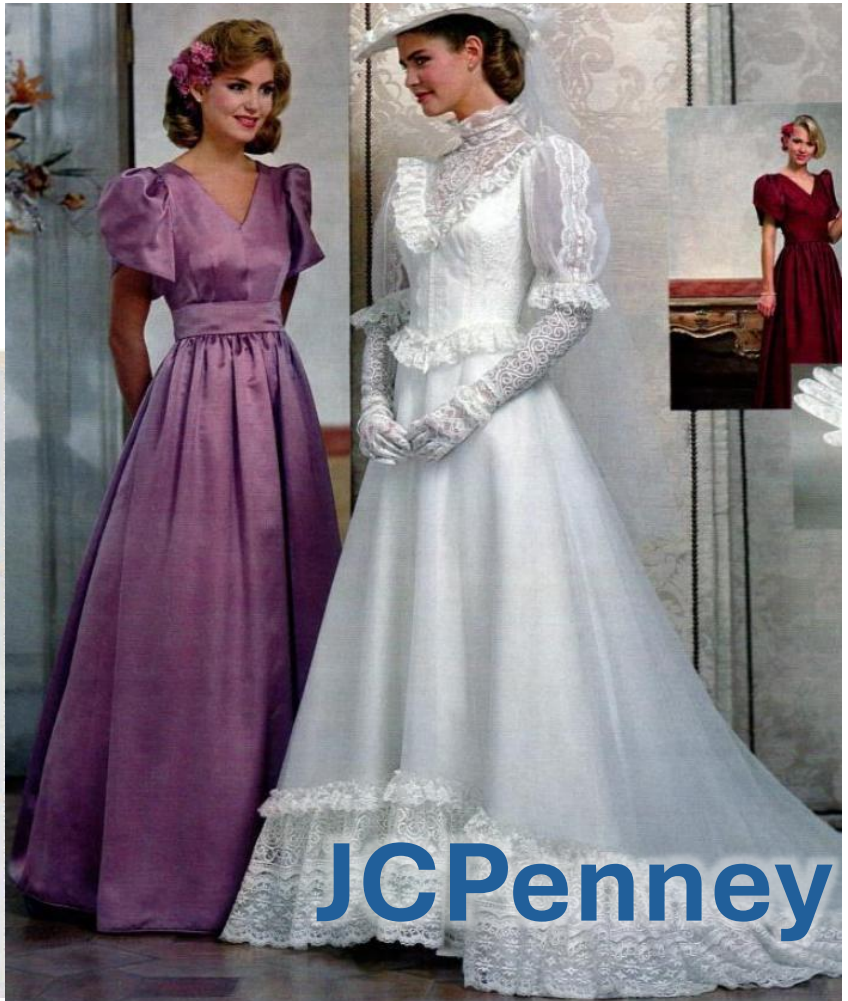


- JC Penney expands from 5 to 12 catalog order centers.
- JC Penney has specific centers for some products

AT&T's Business Subscribers *Love* their single-number 800 Service







Everyone is using 800 Service to place orders and get customer service



Oops, Aunt Mildred needs the Bridal Registry number instead

No problem. The agent can give her that number, *Right?*


Wrong! When the customer is on the line
$
It is JC Penney’s best chance to make a Sale!

How can JC Penney get Aunt Mildred to the Bridal Registry without hanging up and redialing?

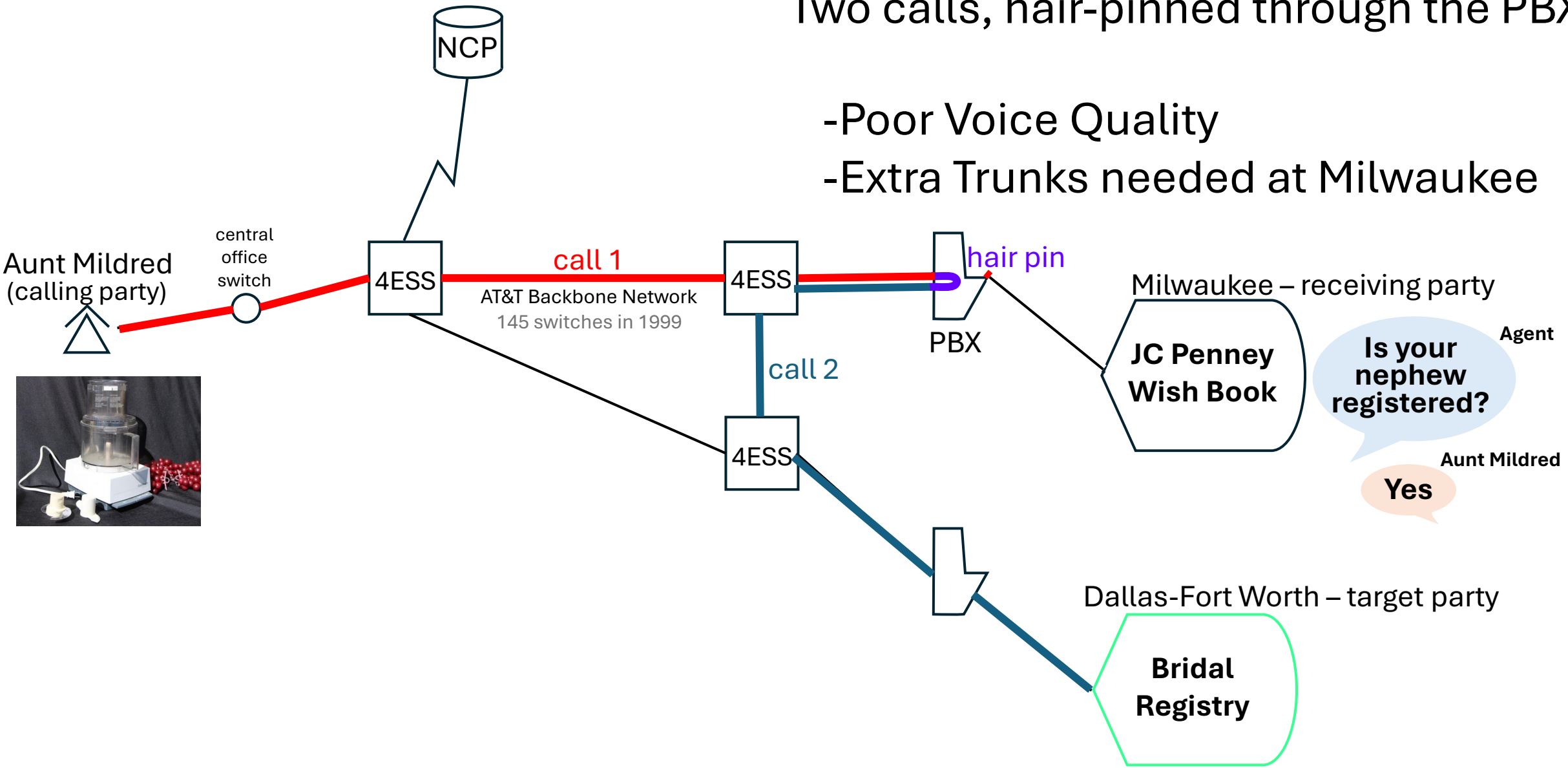
What solution had JC Penney already tried?

JC Penney's Solution:

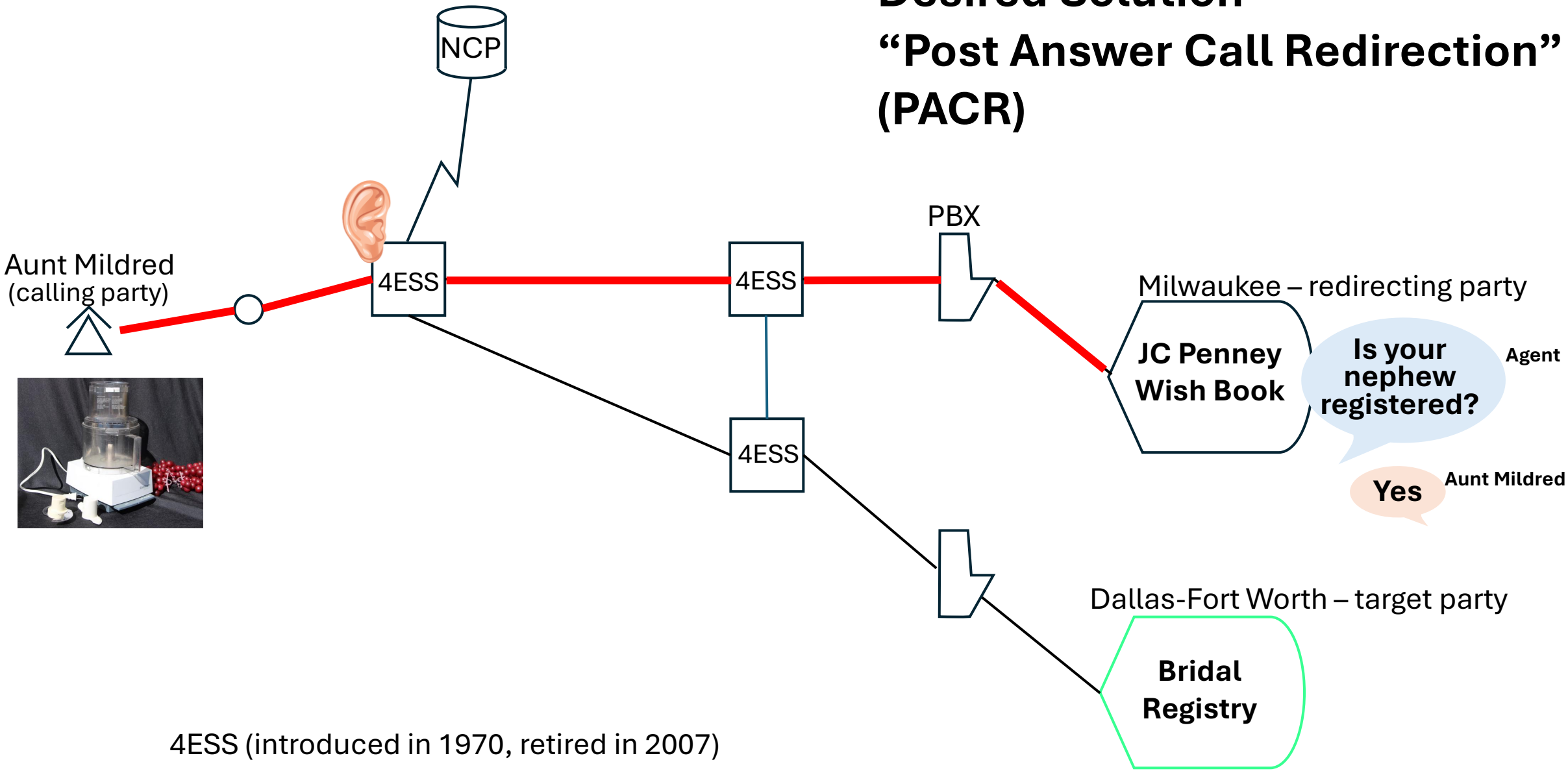
Two calls, hair-pinned through the PBX

-Poor Voice Quality

-Extra Trunks needed at Milwaukee

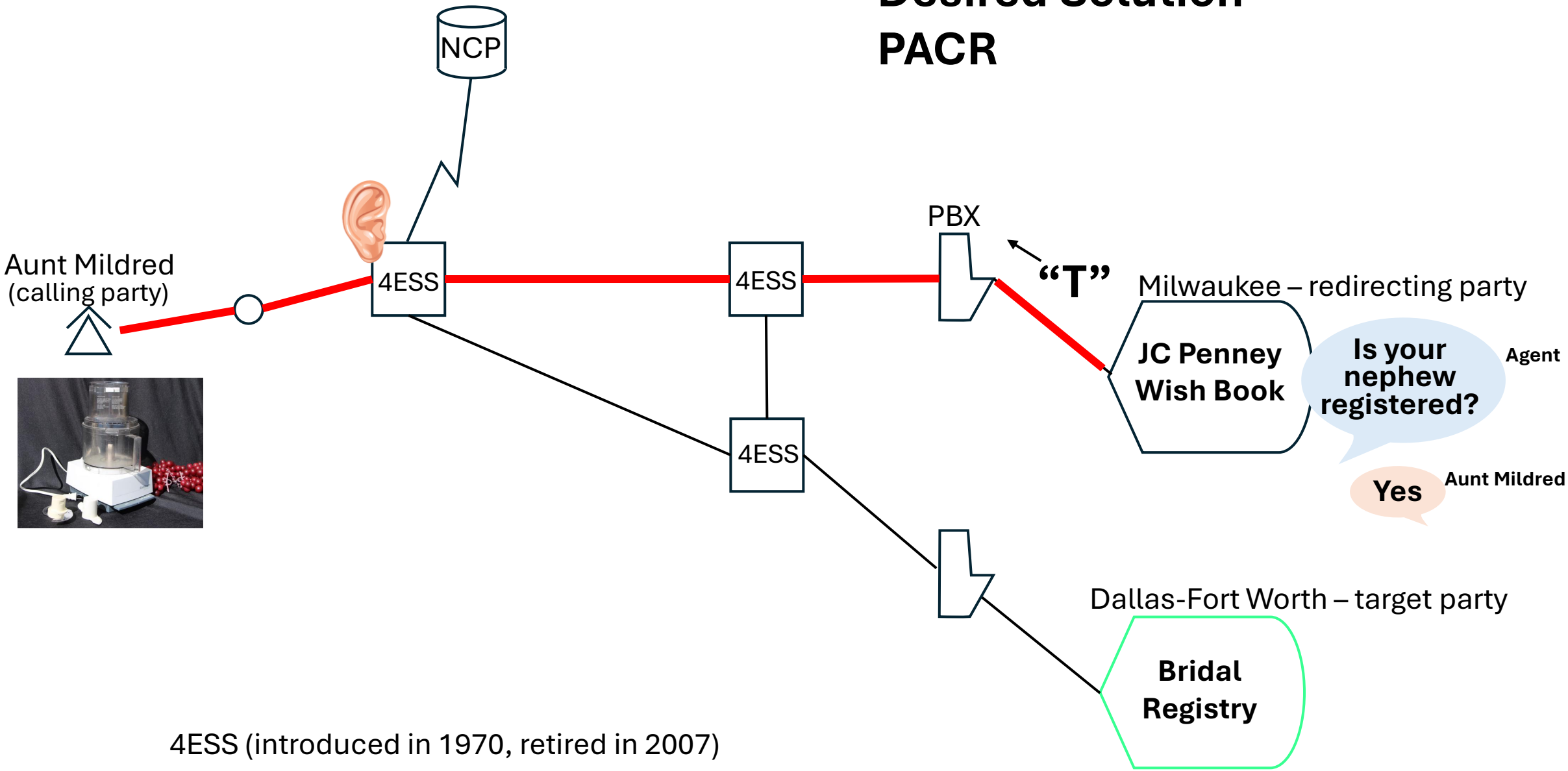


Desired Solution
"Post Answer Call Redirection" (PACR)



4ESS (introduced in 1970, retired in 2007)

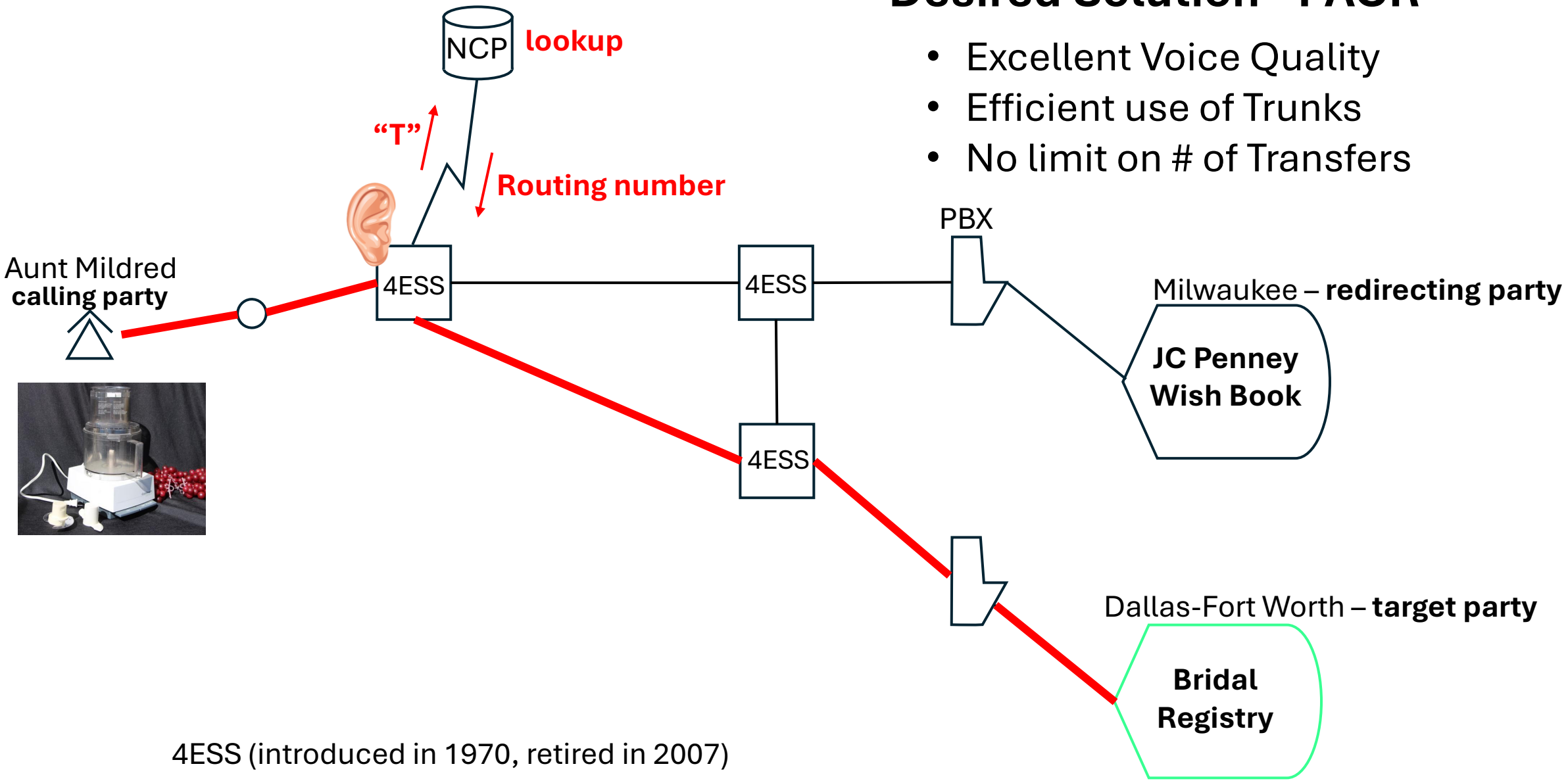
Desired Solution
PACR



4ESS (introduced in 1970, retired in 2007)

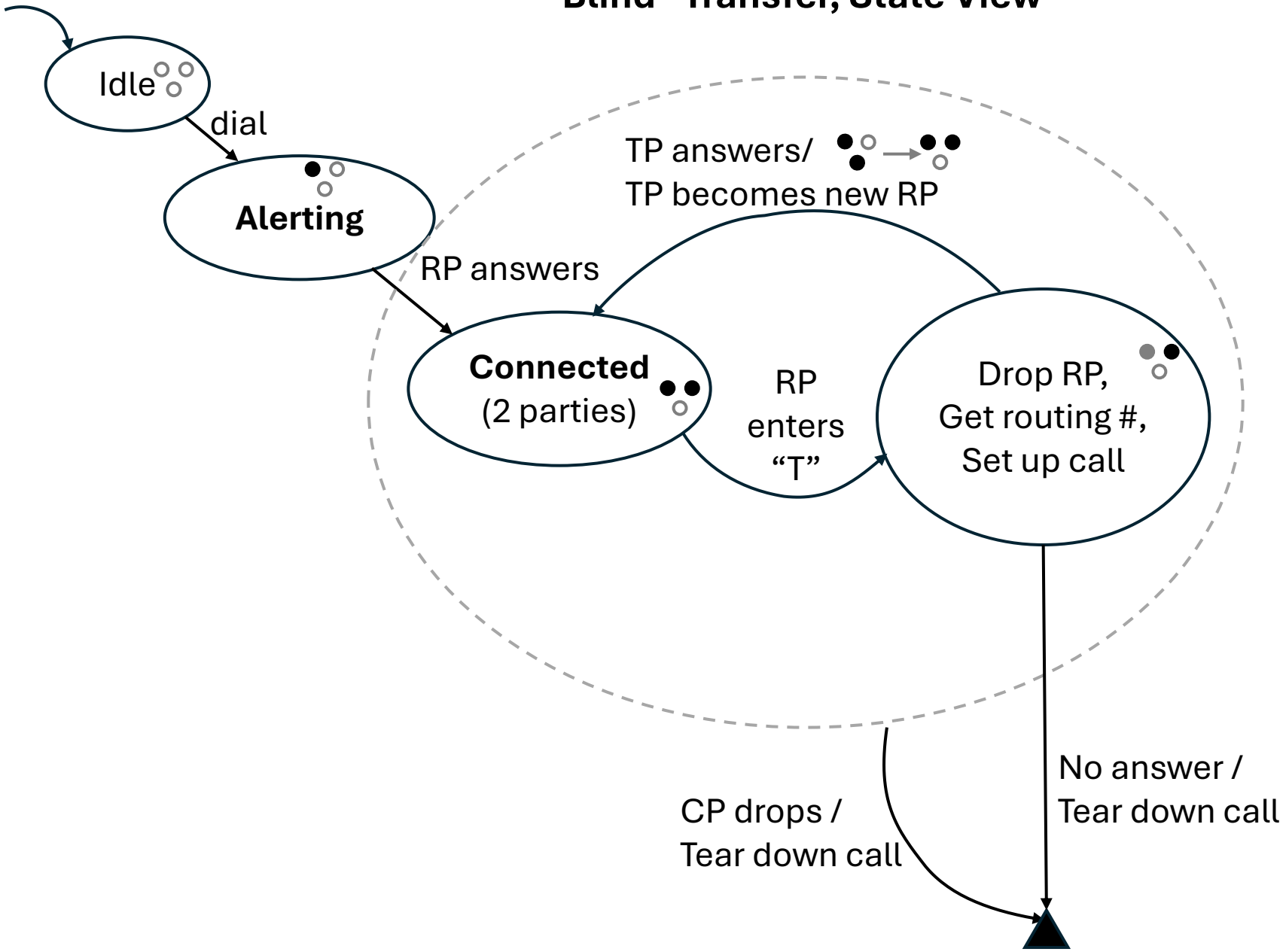
Desired Solution - PACR

- Excellent Voice Quality
- Efficient use of Trunks
- No limit on # of Transfers



4ESS (introduced in 1970, retired in 2007)

"Blind" Transfer, State View

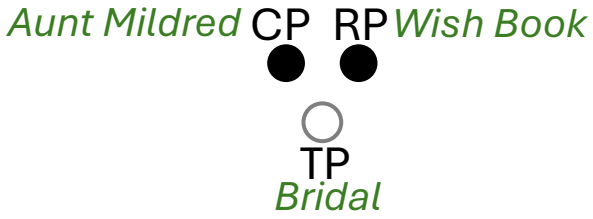


Key:

- Connected
- On hold
- Not present

Example:

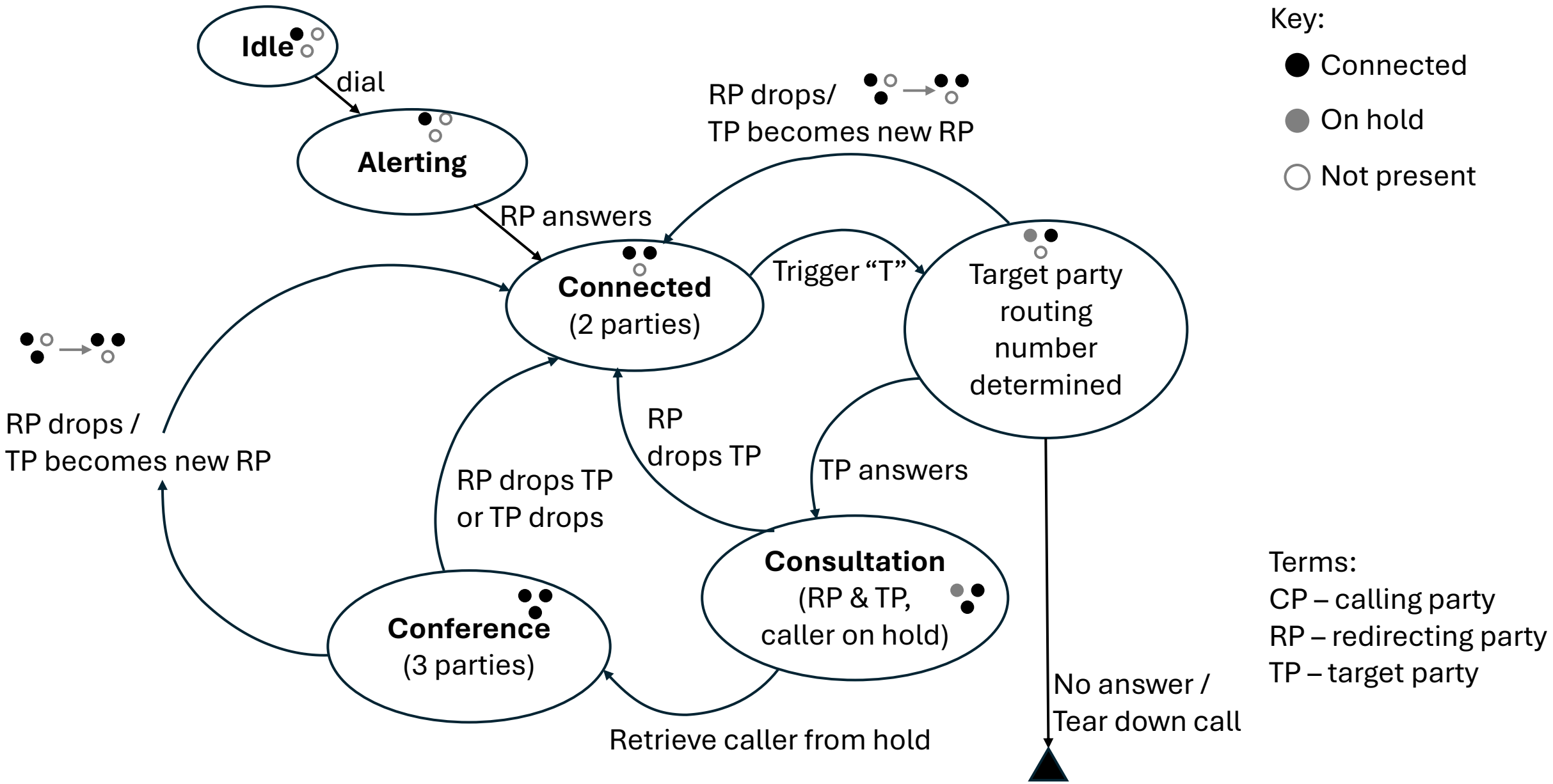
CP and RP connected



Terms:

CP – Calling Party
RP – Redirecting Party
TP – Target Party

Consultation, Conference AND Blind Transfer, State View



After a year of requirements development, 4ESS development estimate was **100 work years**

- But there were only **7 call processing Developers**
- So, that would have meant **14.25 years to market**
- The 100 work year estimate reflected a reluctance to significantly change the core code of the 4ESS.



Systems Engineers at AT&T observed that only about 1 in 10 of the new features we worked on actually got developed and went to market.

Marketing says it’s time to move on...

New PACR Architecture using Conversant

- Began as a what-if conversation
- Then a Feasibility Study
- Then a Cost Analysis
- Finally, green-lighted by Marketing!

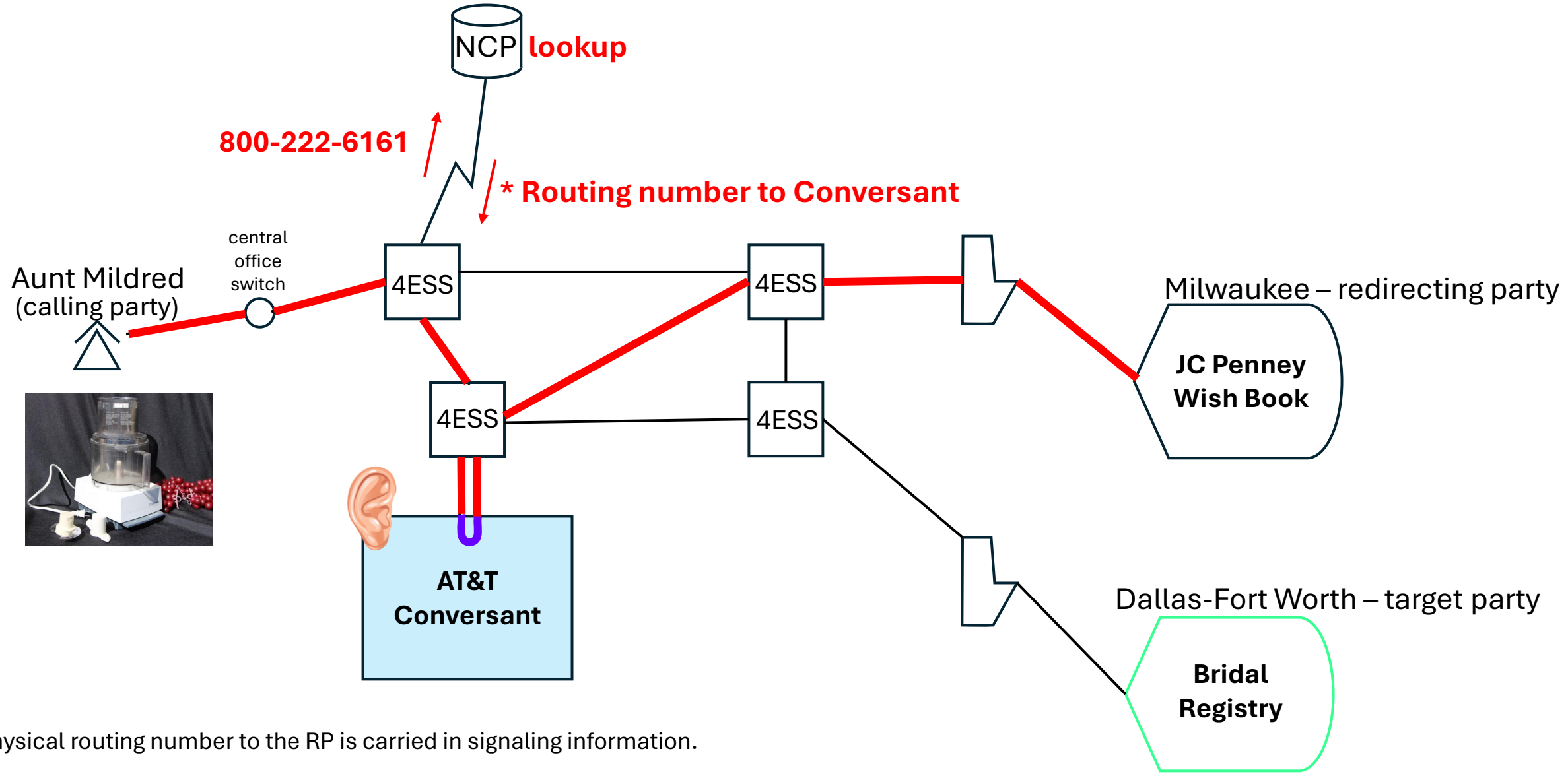
What is a Conversant?

- Built to implement new speech processing technologies
  - Tone detection
  - Voice recognition and text-to-speech announcements
  - Digital call bridging
- Implementation
  - Olivetti PCs connected with a bus.
  - Unix operating system, assembly virtual state machine, C for applications.
  - Customer-side component
  - Highly Programmable logic for managing calls
- “Adjunct” - not an accepted piece of equipment in the toll network.
  - Did not meet Toll Office Reliability Requirements.
- Another AT&T Network Service received approval to use it!
  - This smoothed the way for larger 800 Service to use it too.



The Conversant 1 voice system, model 80.

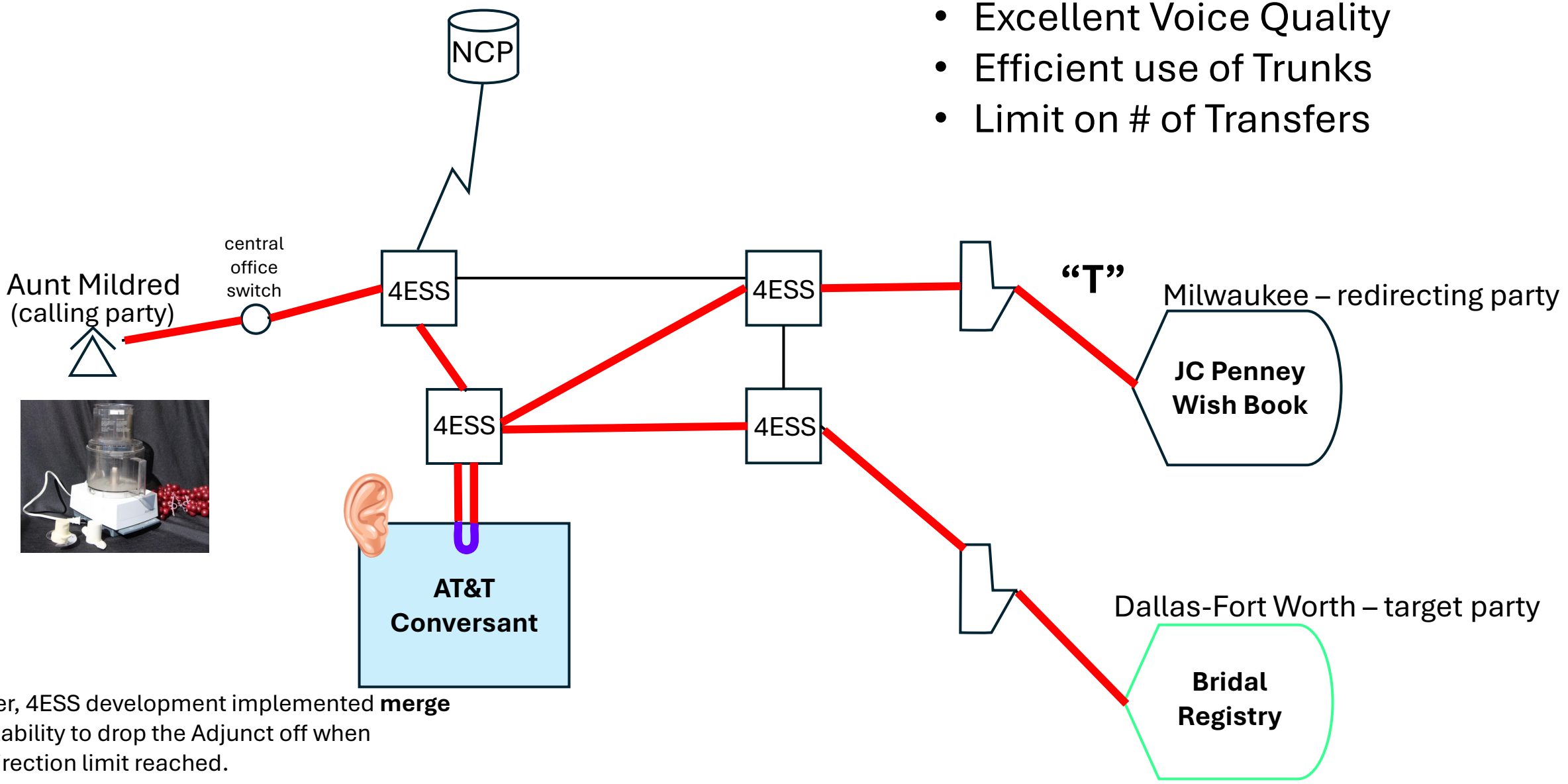
New PACR Architecture using Conversant



*Physical routing number to the RP is carried in signaling information.

New PACR Architecture using Conversant

- Excellent Voice Quality
- Efficient use of Trunks
- Limit on # of Transfers



Later, 4ESS development implemented **merge** capability to drop the Adjunct off when redirection limit reached.

Additional Challenges

The call logic for PACR was complex.

- Monitor Redirecting Party (RP) for tones throughout answered state.
- Not just a simple Blind Transfer – Consultation and Conference too.
- Billing: RP charged for first leg, TP charged for subsequent leg.
- Monitoring for limits on redirections (voice quality, denial of service attacks)
- Signaling changes to ISDN User Part, and AT&T SS7 Network.

Systems Engineering lacked formal tools

- Everything was English prose.
- Had a “Best Practices” manual.
- One senior person who “knew everything.”

New Challenges Call for New Tools!

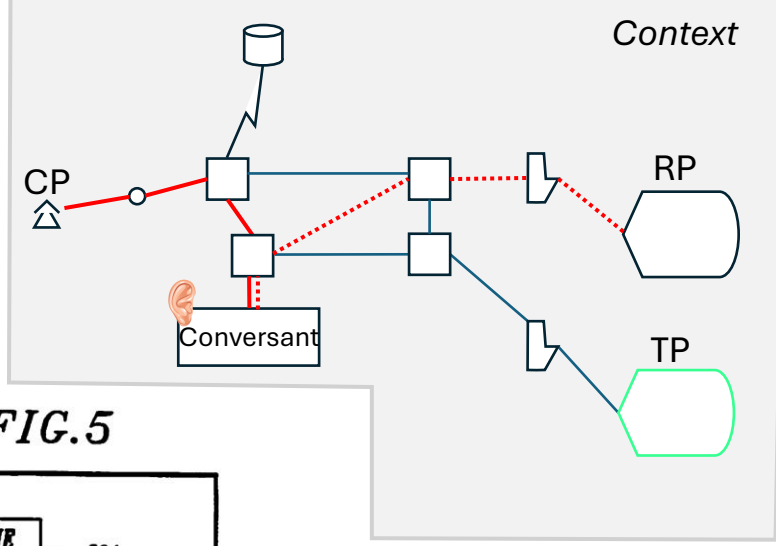
Needed

- A way to capture complex behavior
  - Actors, call states, messaging, and actions.
  - Formal, expressive and thorough.
  - Links between English prose requirements and behavior model.
  - Would work with our “engineering” tools – mainframe computer with dumb terminals, Troff typesetting and Pic for drawing.
  - A way to think through feature interactions and capture them.

Our Solutions

- Developed a paper-based model notation for capturing the Behaviors of the system.
- Developed Feature Interaction Matrix (additional requirements).
  - Captured the mostly pair-wise precedence relations between old features and PACR.

Paper notation for capturing the Behaviors of the system - from the patent



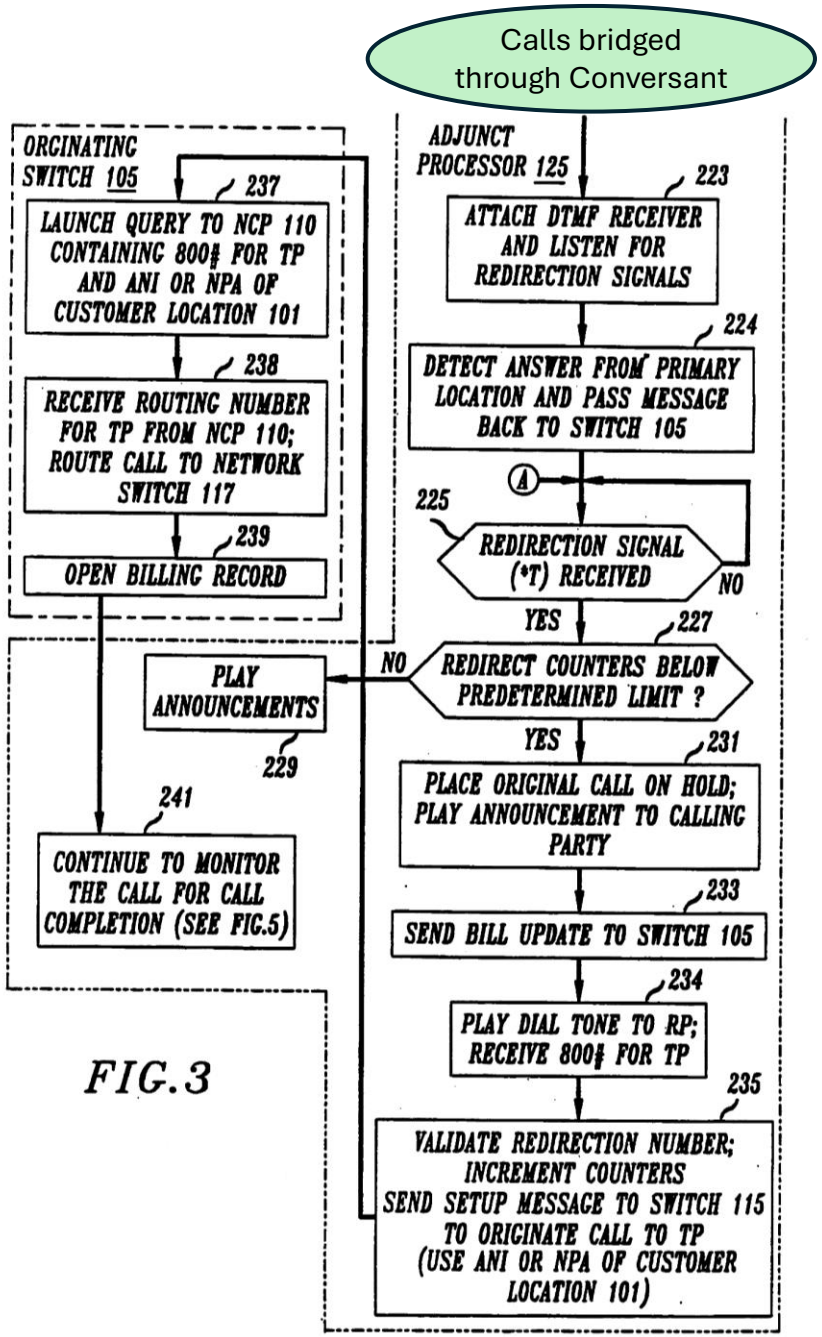


FIG.3

FIG.4

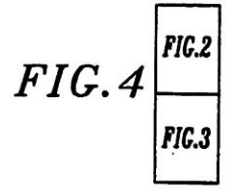
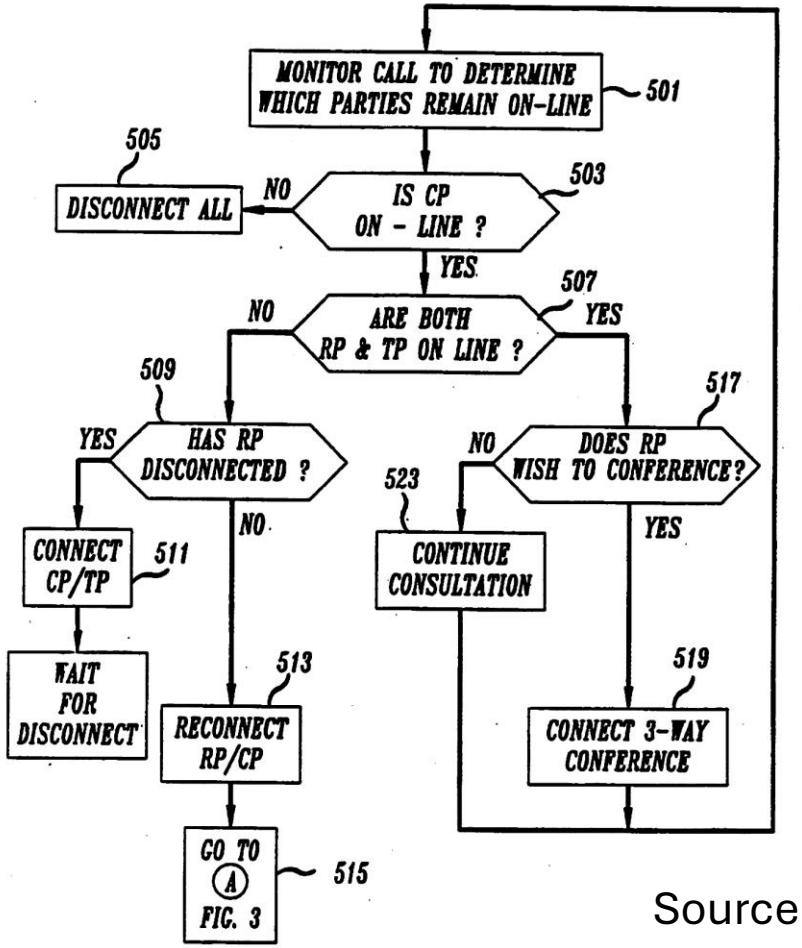


FIG.5



Source: US Patent 5432845

Reflections

- From the failed, architecture I learned what didn't work and why.
- I am persistent by nature, and persistence sometimes pays off. *Keep Trying*.
- Broken processes cause failures even when Tools and Engineering is sound.
  - The original roll-out of the feature was missing the consultation/conference capability – Added later.
  - "Throw it over the fence"
    - Systems Engineering left the project after the requirements were approved.

Next Network Switch (NNS)

- It is now 1993 and AT&T wants a new circuit switch to replace the 4ESS
  - PACR experience was one of the reasons.

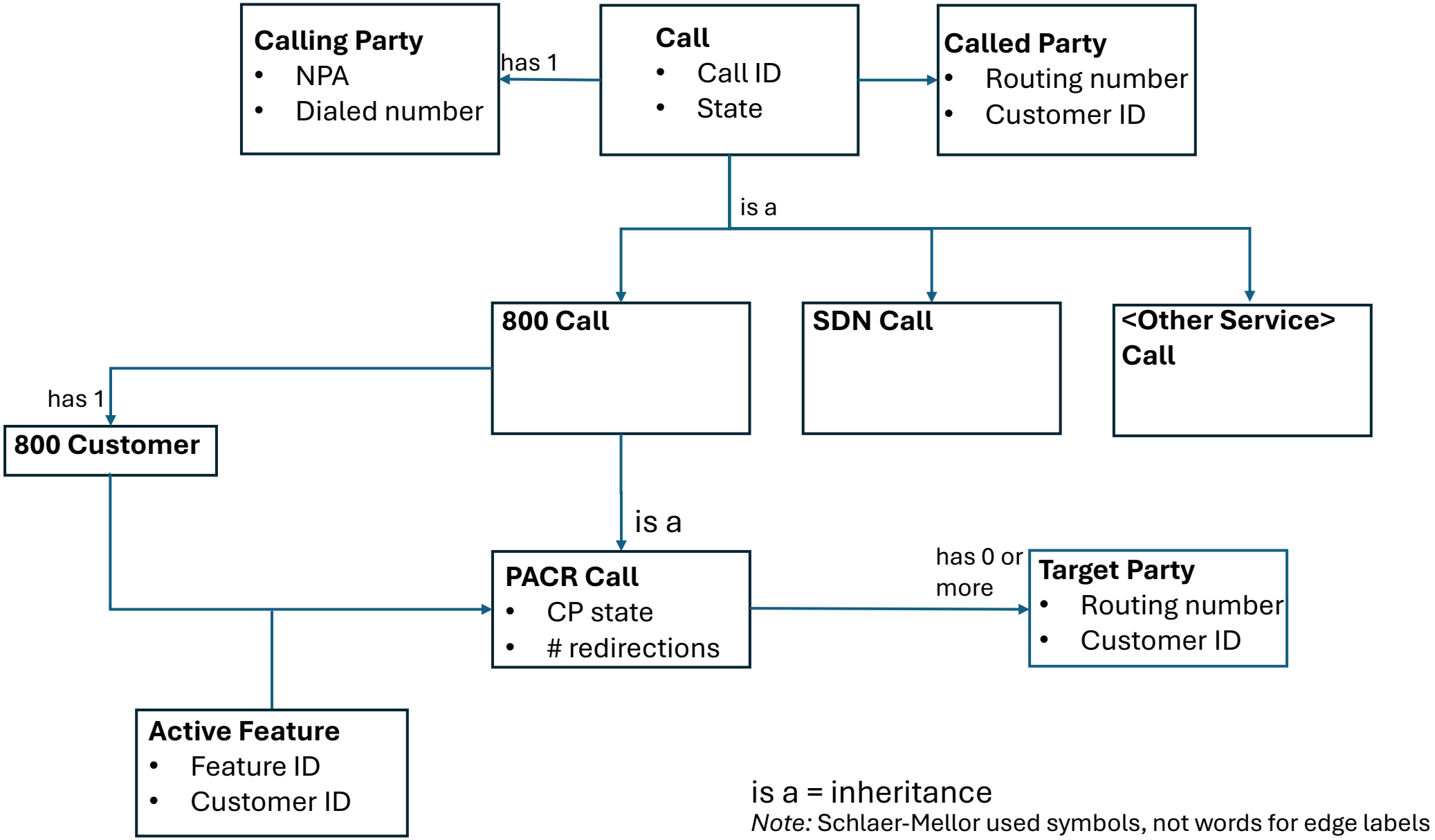
- My role: Reverse Engineer the 25 years of 4ESS Features and Capabilities -
  - Work with 4ESS developers to model call processing for Business services.

- 4ESS code written in a 1970's era in-house
  - purpose-built language stack
    - assembly
    - ESS Programming Language (EPL),
    - EPLX – higher level application/feature programming

- Use *new and exciting* Object Oriented approach and tools, C++
  - Schlaer-Mellor technique, training and tool → later, ObjecTime
  - Shift from structural paradigm to object oriented.
  - This was unchartered territory!

Information (Entity Relationship) Diagram for a Call

Entity relationship types and cardinality

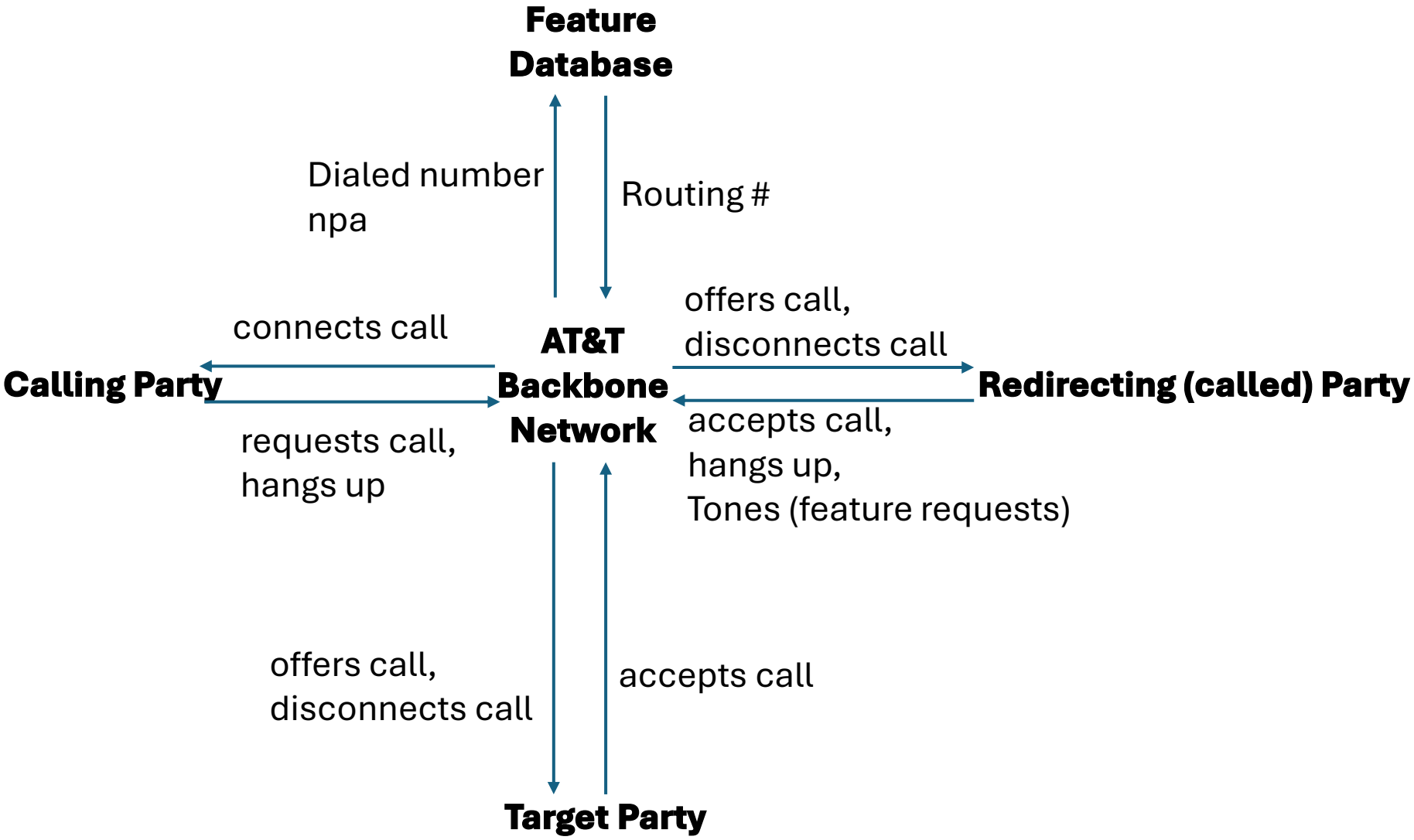


is a = inheritance

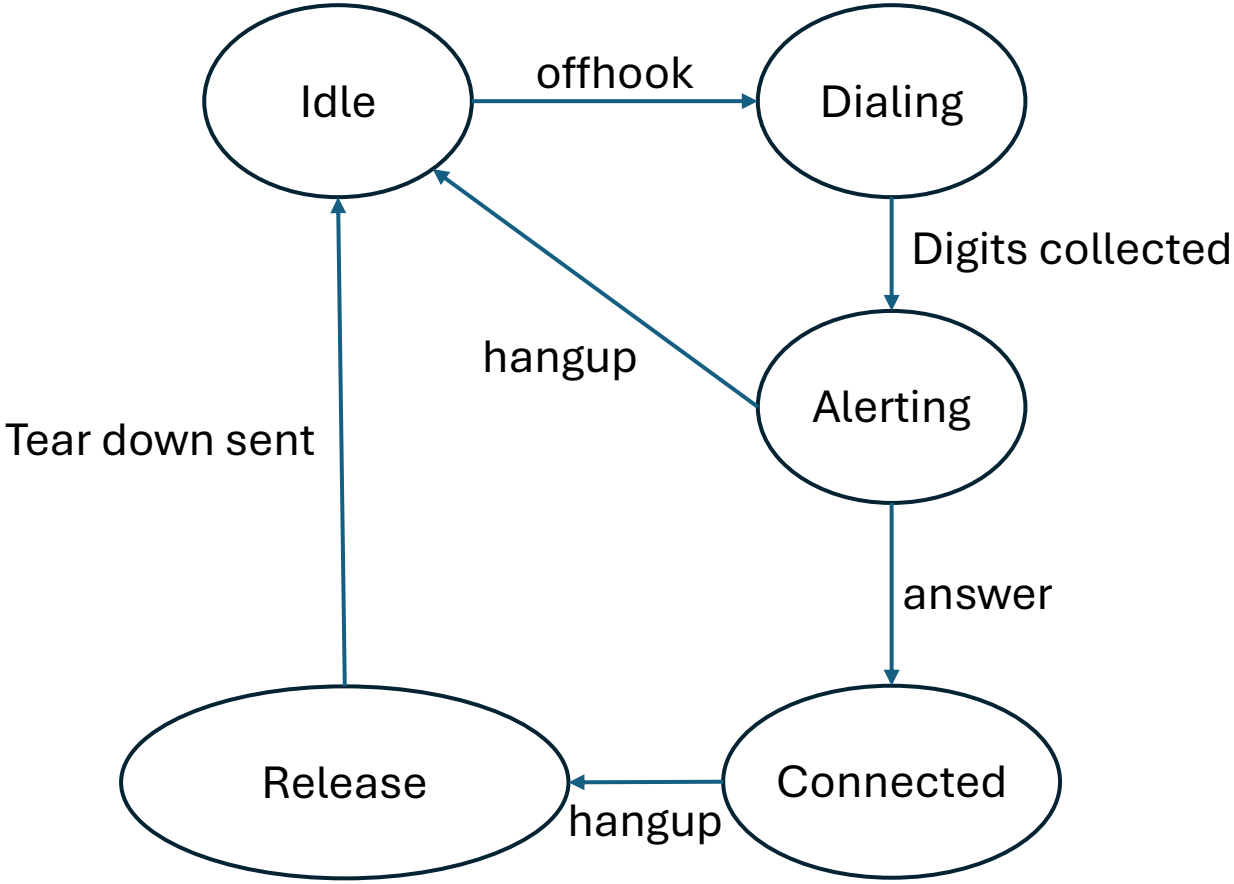
Note: Schlaer-Mellor used symbols, not words for edge labels

Communications Diagram

Which entities communicate and the messages they send



State Machine



Note:

- This is simplified version of a Call State Machine.
- Generally shown with 2 interacting state machines: calling party and called party.

Now we have a *formal way* to specify:

- All objects in the system and their attributes
- How all the objects relate
- Communication between objects
- The States and Events of each Object

This is everything we need to specify the Next Network Switch

Or is it? We are Still Missing Something

- Telecom is highly behavior centric.
  - Remember the domain specific diagrams we developed for the PACR requirements?
  - We needed to specify the Systems Level Behavior to discover the requirements!

- The Communications View doesn't include *ordering* of messages between objects

- State diagrams are in the weeds, below the Systems level of abstraction.

- And this isn't in Schlaer-Mellor technique or their tool.

On a Friday in 1994, 1127 researchers (Gerard+) visited our Systems Engineering team in Holmdel, NJ

By the following Monday, Gerard delivered a prototype of a formal MSC verification tool based on the ITU Z.120 standard.

- With a bonus race condition checking feature

Bell Labs, Holmdel, World's Largest Transistor (also a water tower)



JPL (2003-2017)

Moving to JPL was a big change for me.

- Government funding and oversight.
- Steep learning curve.
- Complete culture shift.

And I had a peculiar, weird kind of baggage…

I was assumed to be a mini-Gerard.

First, I was invited to join a **model checking initiative** because it was assumed that I was a SPIN expert.

On a Flight Project, I was asked to write the **coding standard**!

Who actually wrote it? Gerard

- This was his first work on a coding standard at JPL.
- Future work included: Power of 10 Rules , JPL Coding Standard, SCRUB, and to check them, COBRA.

My real role was *Friend of LaRS*.

Highlights of JPL

MSAP - Multi-mission System Architecture Platform

RCAT Tool

Mars Science Laboratory (Curiosity Rover)

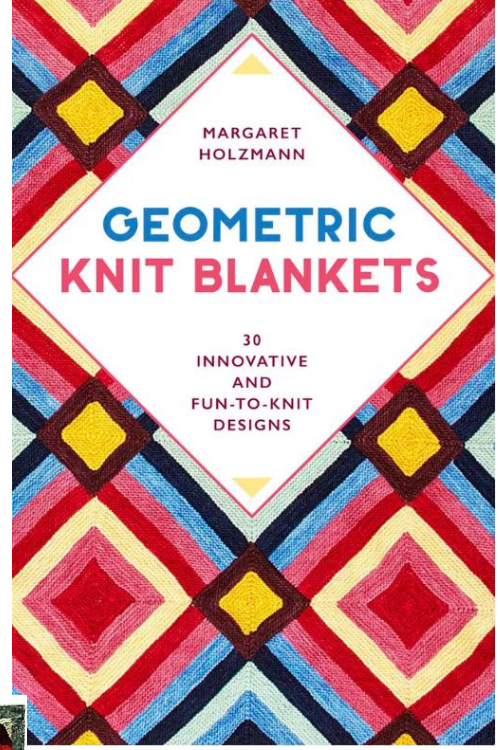
Group Supervisor (software architecture)

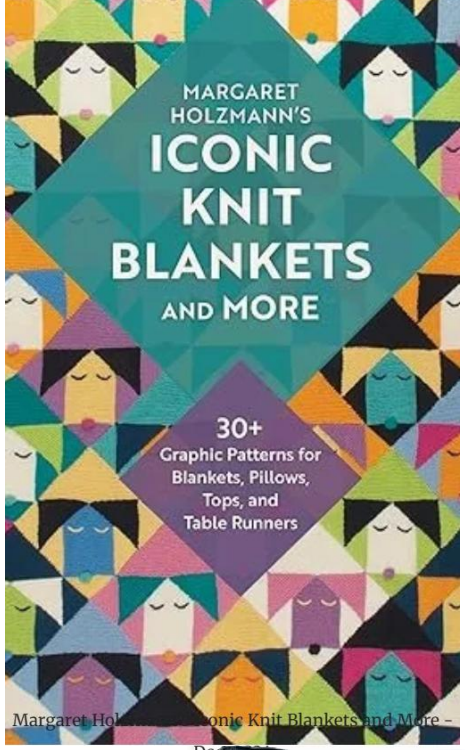
Dark Project

Gerard and I retired in 2017 to *pursue other things*… for me it is …

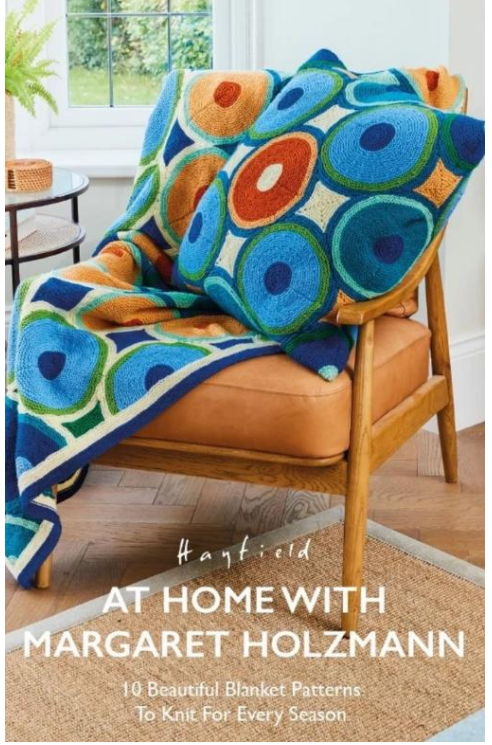


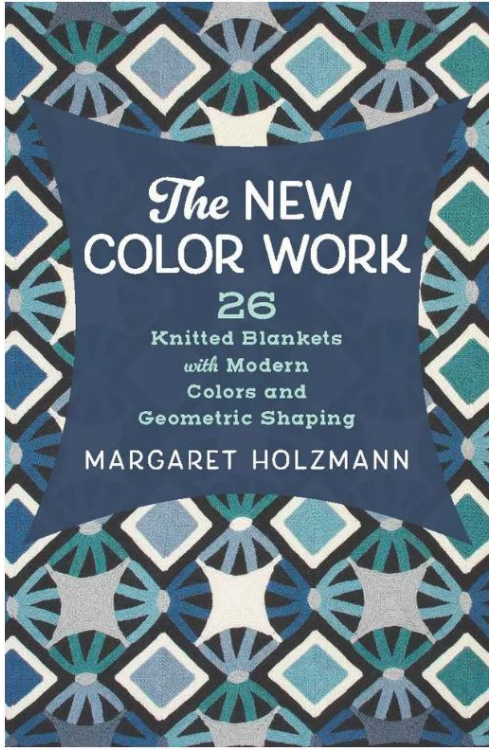
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Margaret Holzmann's Iconic Knit Blankets and More - Dec





The New Color Work - Dec, 2025







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