TSN: Lecture 15
State machine

Topics Covered

- State machine
- Finite State Machine (FSM)
- FSM Description Formats
- Pictorial FSM Example

State Machine

- Standards, user documentation, or software design documents can be written in natural human language, but this often leads to misunderstandings and differing implementations
  - Readers disagree on meaning of natural language, regarding sequence of steps, etc.
  - Actual operational test of compliance to standards requires testing via inter-working against pre-existing implementations
    - Often, first-to-market implementations actually supersede the written standard when discrepancies occur
- A better form of description is needed for:
  - Software algorithm design
  - Description and documentation of existing systems
    - for testing or design of compatible equipment
    - for user training
- Finite state machine (FSM) formalism (also called Discrete State Machine -- DSM) serves this purpose
- SDL-Specification and Description Language, ITU-T standards Z.100 and SDL 2000, formalize a graphic flow-chart-like symbolism for this purpose.

Finite State Machine (FSM)

- FSM formalism can describe a computer or a telephone switching system quite well
- A FSM has a number of distinct states
  - States are distinguished from each other by the unique binary value of:
    - *At least* one bit somewhere in the CPU, RAM or mass storage (disk, etc.) is distinct (1 vs. 0 value) from the corresponding bit value in another state
    - In an electro-mechanical telecom switch, at least one relay/switch contact is distinct (ON vs. OFF)
- A FSM is "driven" from state to state by *events*
  - An event is often an external cause such as a customer dialing a digit, lifting or replacing a handset, etc.
    - The expiration of a timer/counter is also an event

Some Simplifications

- Strictly speaking, each combination of busy vs. idle telephone lines in a switch is a different state of that overall state machine
  - Because of the similarity of operation of all telephone lines, we can simplify the description by describing the telephone switch in terms of just the 2 (or 3, etc. lines for a conference call) involved in the conversation
  - The distinctions due to different optional vertical features (call waiting, etc.) can be handled by means of a general FSM description which handles *every* possible feature, with clearly defined options to allow or deny each specific feature dependent on a data table entry defining the class of service (COS) for that line*.
- We consider the states of one telephone and the aspects of the switch which relate to it, and also the events at the callèd telephone as well.
- The general historical approach to FSM design is to describe what historical electro-mechanical switches do, and then program the digital switch to present the same behavior to the customer
- When new features are designed, feature conflicts sometimes arise. These include discovery of ambiguous operations, etc.
  - Feature conflicts are usually resolved by re-design of the feature at the human interface level.

*Some local service providers (e.g. SouthWestern Bell -- SBC) now allow *all* subscribers to use most previously "optional" services, charging on a per use basis until a maximum monthly fee is accumulated.

FSM Description Formats

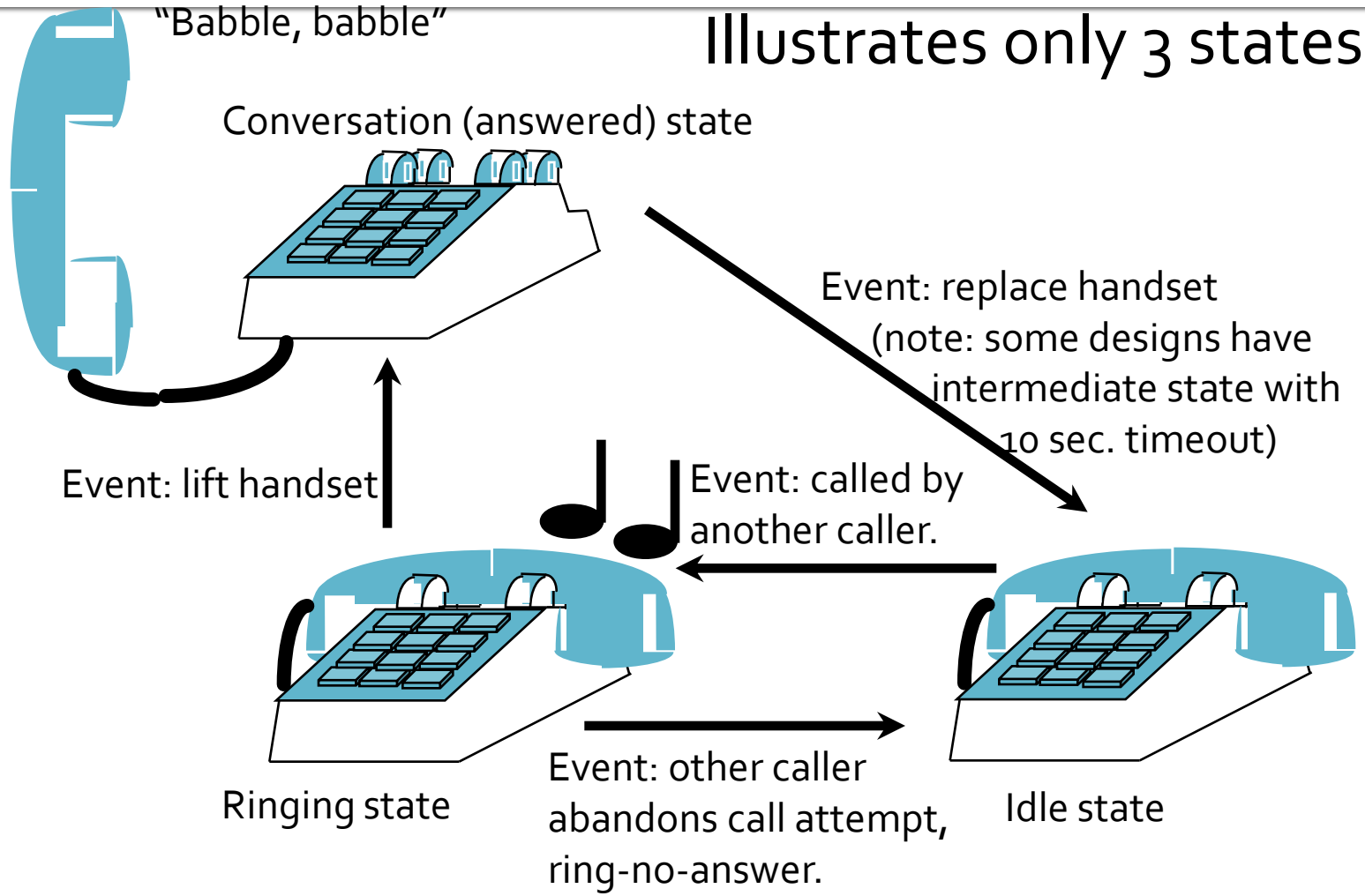
- Logically equivalent (isomorphic) descriptions can be made in several forms

1. Graphic point or picture for each state, with directed lines or arrows representing event-caused transitions between states
   - Useful for human visualization, particularly with "cute-sy" pictures.
2. Table with column for each state, row for each event (or the reverse), and entries describing the target state and related information.
   - Often very large if all events are treated explicitly, and often has many null (not possible) entries. Good for certain table-driven computer software systems.
   - Usually *not* instructive for human visualization
3. Flow-chart like description such as SDL
   - Convenient starting point for software development
   - One-to-one correspondence to formal software language is under study (e.g. ITT CHILL language occasionally used)

Simplifying Conventions

- *Certain* events invariably lead to the same result, regardless of current state (whenever logically consistent)
  - Example: "hang up" of the handset leads to disconnection ("this line idle") state
  - To avoid pictorial clutter, this is omitted but implied in graphic point-line diagram. Shown only where essential for understanding.
- Multiple states can be symbolically combined into one "covering" state to clarify the explanation aspects
  - All the internal details must still be explicitly defined for a working description (perhaps separate diagram)
  - Example: dialed digit collection ("digilator")

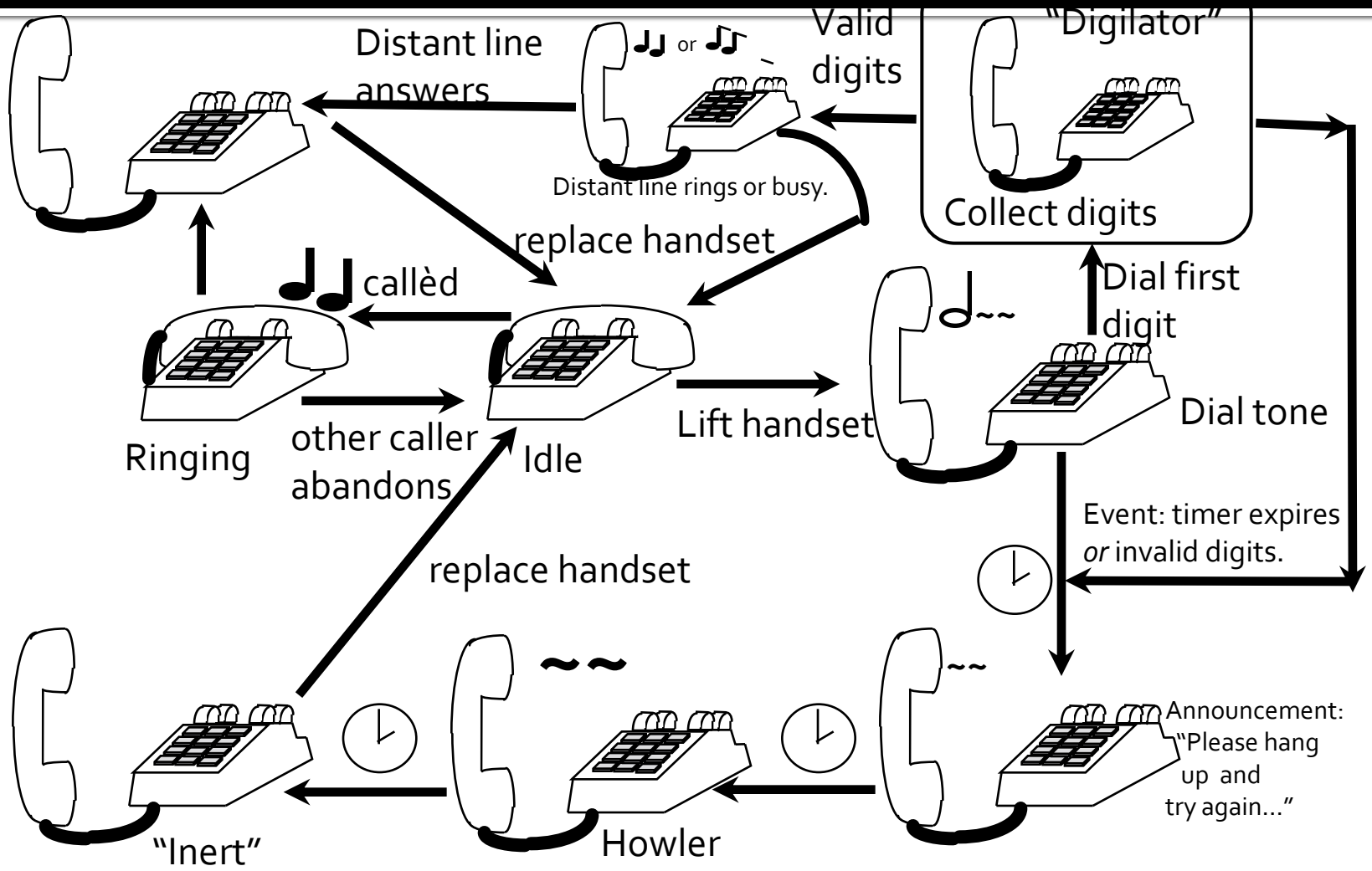
Pictorial FSM Example



Originate-Answer Distinctions

- Most PSTN "wireline" switches actually handle disconnect differently for an originator vs. an answerer. Such switches disconnect:
  - immediately when originator disconnects
  - after (typically) 10 second timer expires, when answering person disconnects.
  - Distinction is software controlled based on a bit set in RAM
- Mimics a historical property of some electro-mechanical switches
  - Allows callèd person to hang up and then quickly run from one extension set to another on same line without disconnection
- Many PBX and Cellular/PCS switches do not distinguish originator vs. destination (except for billing!!)
  - We do not distinguish in our diagram for simplicity
  - If distinguished, two separate conversation states would be required in the diagram

Example Extended

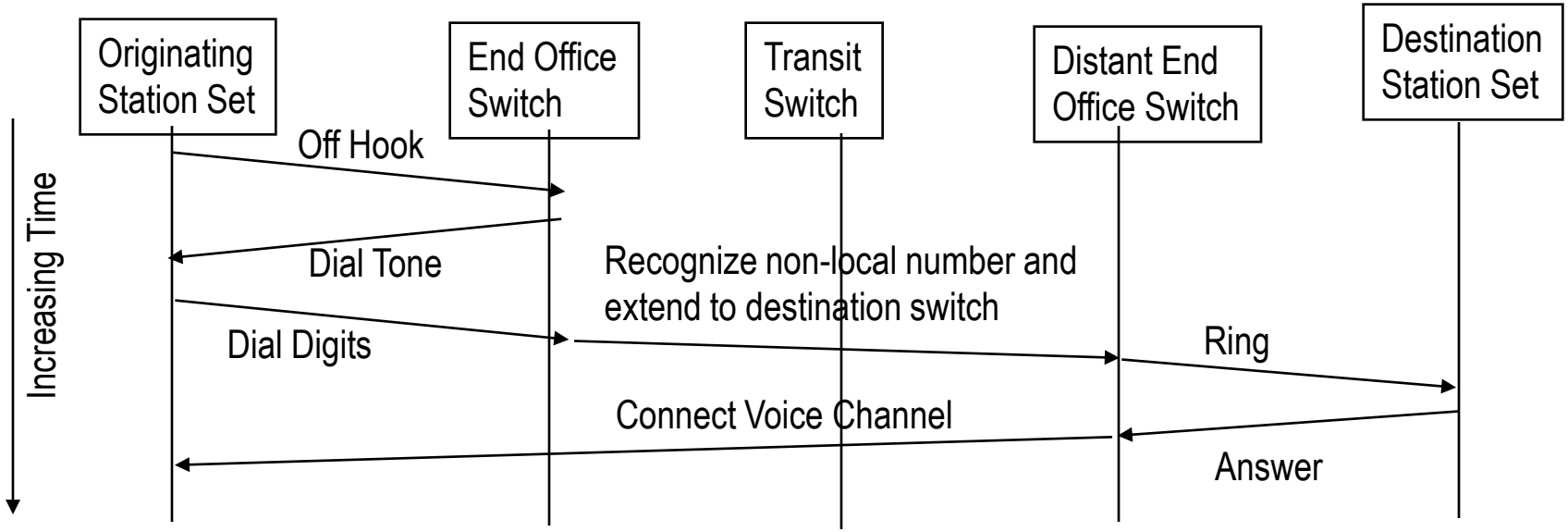


Other Representations

- Not shown explicitly in these notes are two other FSM representations of a telephone switch:
- Tabular representation could have (for example) a column for each state, and a row for each event
  - Entry for Idle column and "Lift Handset" row is "Go to Dial Tone state"
  - Entry for Dial Tone column and "Lift Handset" row is "not applicable"
  - Entry for Dial Tone column and "Dial first digit" row is: Start timeout for inter-digit max time, go to next Digilator internal state
- SDL description comprises a distinct flow-chart-like diagram for the computer processing steps which must follow each event
  - Proto-representation of the software in the interrupt handling routine invoked by that event.

Time-Space Diagrams

- In some cases the sequence of events and messages between different parts of a telecom system is displayed via a time-space diagram.
  - Time (not to correct scale) usually increases in downward direction
  - Various horizontal positions (not to scale) represent different physical devices (subscriber set, end office switch, transit switch, etc.) in the system
  - Only one (usually representing a "successful" case) event sequence is displayed.



Variations on a Theme

- Use of diagonal lines (as in previous page example) emphasizes transmission time delay aspect
  - Often called a "zig-zag" diagram
- Horizontal lines may also be used
  - Then often called a "ladder"diagram. Still exhibits sequence of events but de-emphasizes transmission delay
  - Another name: "Ping Pong"Diagram
- Similar diagrams in other subject areas illustrate sequential events at different locations
  - e.g., Feynman diagrams in quantum physics
- Time-Space diagrams cannot clearly illustrate all exceptional cases in one figure
  - e.g. destination busy, or ring-no-answer, timer in software expires, etc. etc.

Distant Line Ring or Busy

- When the destination telephone is in another switch and the trunk signaling is one of the more primitive types (*not* common channel No.7), the *origination* switch cannot distinguish distant ringing from busy
  - The human caller must listen to the call progress tones to distinguish busy/ringing
- When the callèd telephone line is in the same switch or CCS7 signaling is used, this switch can distinguish, and two states should be drawn.
  - Two distinct states are *not* illustrated in these notes.

Digilator Digit Collection

- A contraction of the words "digit" and "percolator," the Digilator "state" is really a collection of many internal states and events.
- Digit collection strategy can be described as a tree-structured data collection decision process
- Any pause before or between digits which exceeds maximum time causes a state transition to a recorded announcement
  - Internal timer (typically 6 to 20 seconds) is started after each digit but the last, and reset again when the next digit is sensed
  - Expiration of the timer causes a "time out" interrupt
- Valid digit strings are described by both
  - Numbering plan: assignment of specific number groups to local, long-distance, and service lines
  - Dialing plan: assignment of specific digits (usually prefixes) for purposes not described in dialing plan:
    - Example: dial 9 prefix to get outside line in a PBX
    - Example: dial initial 1 (North America) or 0 (many European nations) for non-local or special service calls (1-411, etc..)

Digilator Information

- In North American Numbering Plan (NANP)
  - Initial digits 2,3,… 9 (not 1,0 ; traditionally represented by N) are valid for local directory number
    - Subsequent digits can by any of 1,2,3,…9,0 (called X). First 3 digits form exchange code NXX, remaining digits XXXX. Special treatment for 3-digit service codes NXX=911, 311, and in some areas 611, 411 etc.
    - Digit Collection will be stopped after 7 digits (local call) are collected
      - Recently, mandatory 10 digit local dialing in numerous cities like Dallas.
    - Then further testing or connection required to determine if this number is in service, corresponds to a valid NXX, etc. Data for this decision may not be available in the originating switch.
  - The complicated cases are initial zero (0) and initial one (1)
  - Initial 1 *may* imply:
    - service call: 1-411 for directory assistance, 1-611 for repair (initial 1 not used universally)
    - Non-local (inter-exchange carrier) *but* in e.g. Los Angeles, just non-local
    - first digit of 11XX, a rotary dial substitute for special feature prefix/code such as *69 (1169) for "call back most recent caller"
    - first digit of 1010XXX prefix for selected inter-exchange carrier (e.g., 1010222 for MCI, 1010288 for ATT, etc.)

NANP Initial Zero

- Initial zero (0) has several subsidiary choices, depending upon succeeding input:
- Followed by no other digits (typically 6 second timeout) connects to local operator/attendant (0|)*
  - Followed by second 0 and timeout (00|), connects to preferred inter-exchange carrier's operator/attendant
  - Followed by 11 indicates international call (011-) prefix
    - 010- is international operator assisted prefix
  - Followed by any valid foreign directory number (country code, area code, local number) indicates an operator assisted call (so-called "zero-plus" call)
    - Example, person-to-person or English-language-only international call, etc.

* The non-standard symbol "|" is used here to represent a timeout with no succeeding digits.

NANP Areas

- US, Canada, and certain coastal* and Caribbean islands are under the NANP
  - Each area has a 3 digit area code of form NXX, sometimes represented by the 3 letters NPA. In some documents, the 10 digits are represented ABC DEF GHIJ.
    - Historically the B digit was restricted to 1 or 0 due to historical use of NNX for local office codes. No longer done (now NXX)
    - Size of an area is dependent on total directory numbers in use in that area. High population density areas have required many area code splits or overlays in recent years and will again in the future
    - "Caller pays" special surcharges is the source of questionable billing in some Caribbean nations. *Beware* of area code 809 and others…
- Certain pseudo-area codes are used to cover the entire NANP:
  - 800, 888 and 877 for callèd-line-pays long distance numbers.
    - *Actual* target number is determined by a translation table data base using the succeeding 7 digits
    - Call forwarding to existing line can be altered based on originator's directory number, time/date or other factors
      - Your call to Sears Roebuck or Domino's Pizza is routed to the geographically nearest store (central office) to your point of origin
      - When calling some large firms, your call to the same number may go the the east coast customer service department in the morning, and the west coast department in the afternoon and evening.

*e.g. St.Pierre and Miquelon, French possessions off Canada's Atlantic coast. Also Bermuda, etc.

ITU Numbering Plan

- The world is divided into 9 zones, each with a specific initial digit used in national prefix:
  - 1 North America (US, Canada and some islands)
  - 2 Africa
  - 3 Europe (part)
  - 4 Europe (other part)
  - 5 Central and South America
  - 6 Australia and pacific (part)
  - 7 Former USSR
  - 8 China, Japan and Pacific (other part)
  - 9 India and Middle East
- smaller nations have 3-digit code, larger nations have 2- or 1-digit codes.