Engineering of computer networking protocols :
an historical perspective

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with thanks to Colin West and Dave Rayner
http://www.site.uottawa.ca/~bochmann/talks/history.ppt

McNaughton Lecture

24th Canadian Conference on
Electrical and Computer Engineering

Niagara Falls, May 2011

Approximate time line

1960: first high-level programming languages

1965: time sharing operating systems and interactive terminals

1970: first experimental computer networks

1975: X.25 networking standard, proprietary networking architectures, e.g. IBM's SNA

1980: experimental Internet, OSI standardization started, Teletex (a kind of Web service, Telidon in Canada)

1985: Formal Description Techniques (FDTs) developed, experimental tools

1990: commercial SDL tools, beginning of public use of the Internet and Web

1995: Java released, wide use of the Internet, digital wireless telephony spreads – UML (universal modeling language)

2000: XML and Web Services

2005: beginning integration of wireless services with the Internet

2011: there we are . . .

Computer communications
in the 1970ies

Remote access to servers

User terminals
Batch entry terminals
Line multiplexing

line speed: 300 bps
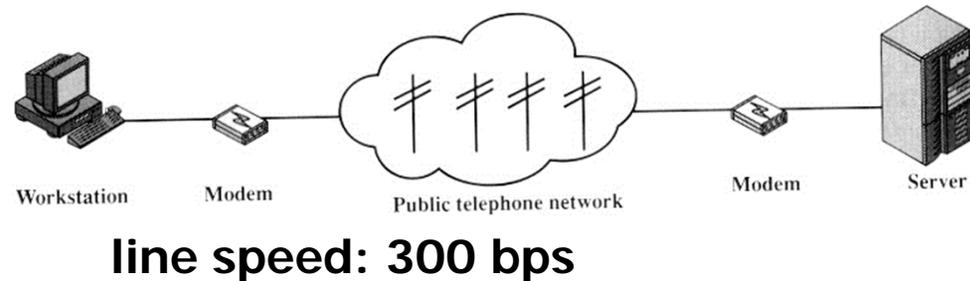
Link protocols (with sequence numbering)

- Alternating bit protocol (1969)
- Bisync, SDLC (IBM)

Computer communications
in the 1970ies

Computer networks

- ARPANET (USA): first long distance computer network – first trial in 1969
- NPL network (UK): first LAN
- Cyclade (France): introduced IP service at the network layer – around 1972

Donald Davies, NPL

Louis Pouzin INRIA (France)
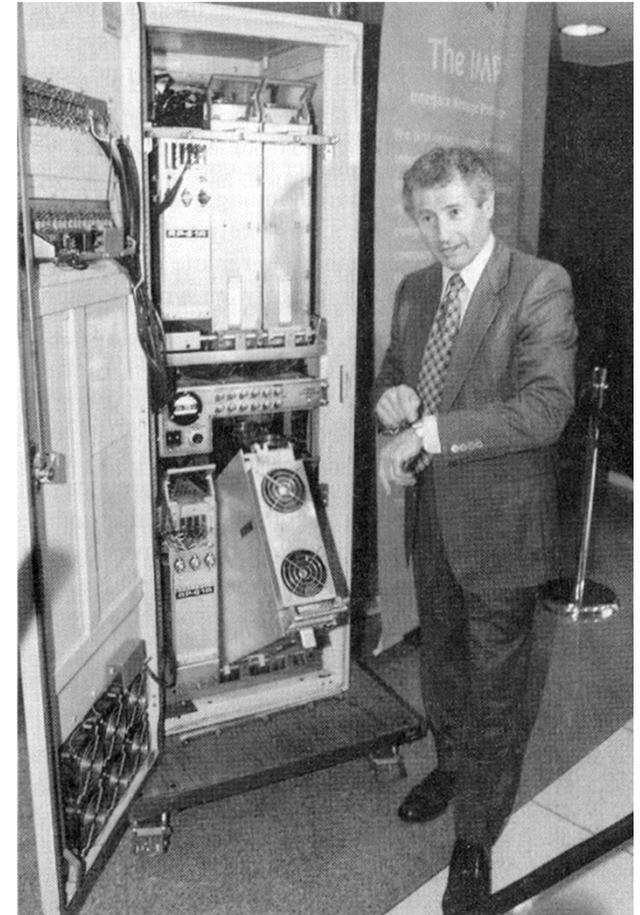
Leonard Kleinrock, UCLA with ARPAnet node

Computer communications
in the 1970ies

Protocol standards

- First network protocol standard: X.25

Vendor networking architectures

- IBM (SNA), DEC, Honeywell, etc.

Application protocols

- Internet protocols: e.g. FTP and SMTP (developed during the 1970ies)

- Teletex – an early version of the WWW (around 1980)

- ASN.1 and OSI Remote Operations: an early version of Web Services (early 1980ies)

My personal experience

in protocol engineering in the 1970ies

- Met Louis Pouzin (Cyclade network) at a conference in 1973

- Analysed ABP in 1974 and developed reachability analysis for FSM models – first paper in 1975

- Experimented with program-proof techniques to verify a sequencing protocol (paper in 1975)
- Applied reachability analysis to X.25 packet level protocol (paper in Computer Networks in 1978)
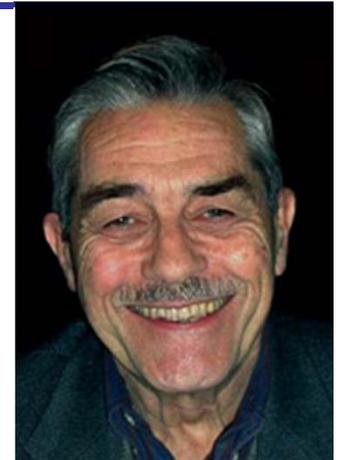
My personal experience

in protocol engineering in the 1970ies

- In 1977, with Gecsei, proposed protocol modeling with Extended FSM models.

  At the IFIP Congres in Toronto, met Zafiropulo from IBM who had worked with Colin West and Harry Rudin on protocol verification.

- Worked as consultant for the Canadian government on the issue of datagrams or virtual circuits in computer networks

- Worked on the formalization of concepts:
  - Protocol: not defined as an interface between two remote peers, but as the required behavior of a peer
  - Service: an abstraction of protocol layers containing several protocol entities (peers)

My personal experience (suite)

Meeting points

- INWG ("International Network Working Group) later IFIP WG 6.1
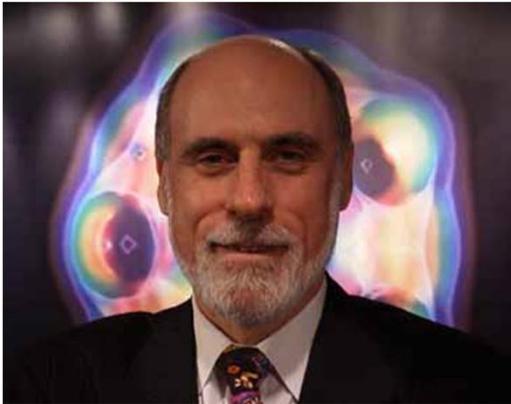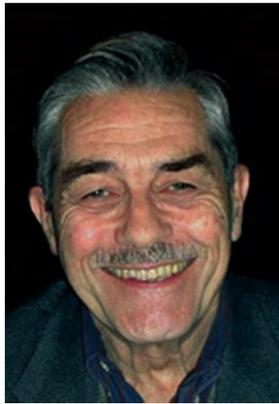
Vint Cerf   Louis Pouzin   H. Zimmermann   Carl Sunshine   John Day
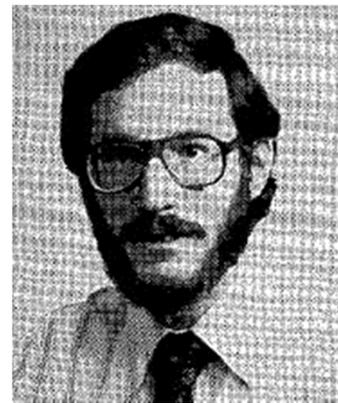
- Conference on "Computer Network Protocols" organized in 1978 by André Danthine in Liège
- PSTV conferences (since 1981) organized by IFIP WG 6.1

André Danthine

From Table of Content of Liège conference

A session on
Protocol Definition
and Verification

F. PROTOCOL DEFINITION AND VERIFICATION

F1 Survey of Protocol Definition and Verification Techniques
C. Sunshine

F2 Verification of Protocols Using Symbolic Execution
D. Brand, W.H. Joyner

F3 Finite State Description of Communication Protocols
G.V. Bochmann

F4 Automated Protocol Validation One Chain of Development
H. Rudin, C.H. West, P. Zafiropulo

F5 Modelling and Verification of End-to-End Transport Protocols
A. Danthine, J. Bremer

F6 Protocol Definition with Formal Grammars
J. Harangozo

G. PROTOCOL PERFORMANCE

G1 Measurements of the Transmission Control Protocol
C.J. Bennett, A.J. Hinchley

etc.

Proposal for an
Internet
Transport protocol (TCP)

INWG DOCUMENTS

A Bibliography on the Formal Specification and Verification of Computer Network Protocols
J.D. Day

Proposal for an Internetwork End-to-End Transport Protocol
V. Cerf, A. McKenzie, R. Scantlebury, H. Zimmermann

Proposal for a Standard Virtual Terminal Protocol

My personal experience (suite)

Meeting points (suite)

- **FTP Group** - part of ISO standardization for OSI (since around 1979 – instigator: John Day)
  - **Subgroup A:** Architectural issues - chaired by Bochmann
  - **Subgroup B:** work on EFSM modeling language Estelle (standardized in 1986) – chaired by Richard Tenney
  - **Subgroup C:** work on LOTOS language (also standardized around 1986) – chaired by Chris Vissers, later Ed Brinksma

- **CCITT Rapporteur's group on SDL** (since 1976)

Richard Tenney
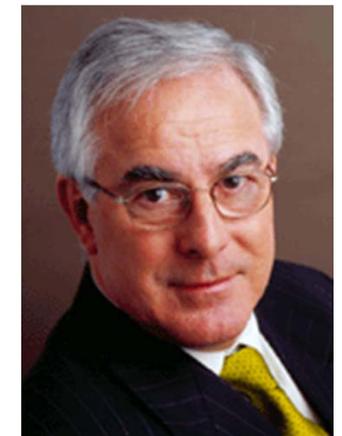
Chris Vissers

A personal experience: **Colin West (IBM)**

- Research team on protocol verification at IBM Zurich: Harry Rudin, Pietro Zafiropulo and Colin West
- West built first reachability analysis tool – used for verifying X.21 protocol (paper in 1978)
- Applied tool to the validation of IBM's SNA protocols
- SNA was defined in FAPL – a kind of FDT with compiler for code generation (paper in 1980)
- Used random testing approach to validate protocol models
- Participated in OSI Session layer standardization
  - Protocol defined in the standard using state tables
  - Validated state tables over night
  - The formal specifications in Estelle and LOTOS in the annexes were never used by the standardization group

What is "protocol engineering" ?

... methods and tools for building communication protocols ...

Answering questions like:

- What is a protocol ? – What is its purpose ?
- How to specify a protocol ?
- How to verify that a protocol is correct ?
- How to construct an implementation ?
- How to check that an implementation satisfies the requirements of the specification ?

What is "protocol engineering" ?

- What is a protocol ? – What is its purpose ?

communication service

PROTOCOL LAYER

two Protocol entities
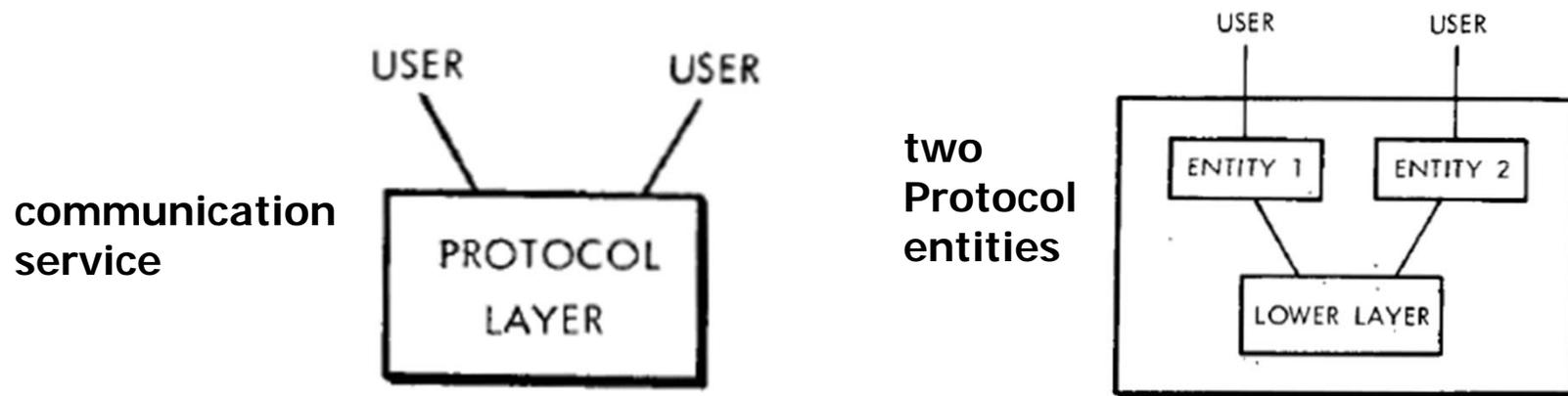
- How to specify a protocol ?
    - an abstract model of behavior with two interfaces
        - service primitives exchanged over upper interface
        - protocol messages exchanged over lower interface
    - definition of encoding of messages (detailed - not abstract)

What is "protocol engineering" ?

- What is a protocol ? – What is its purpose ?
- How to specify a protocol ?
- **How to verify that a protocol is correct ?**
  - Comparing protocol behavior with desired communication service, model checking - concurrency
- **How to construct an implementation ?**
  - Model-based development, code generation tools
- **How to check that an implementation satisfies the requirements of the specification ?**
  - specification-based testing (derive test cases from protocol specification) – in contrast to while-box testing of software

The first PSTV conferences (i)

*I see these conferences somehow as a follow-up of the conference in Liège. The main instigators were probably the organizers of the first three conferences:*

1981 : Teddington near London (Dave Rayner)

1982 : Idyllwild, California (Carl Sunshine)

1983 : Rüschlikon near Zurich (Harry Rudin and Colin West, at IBM)

Dave Rayner
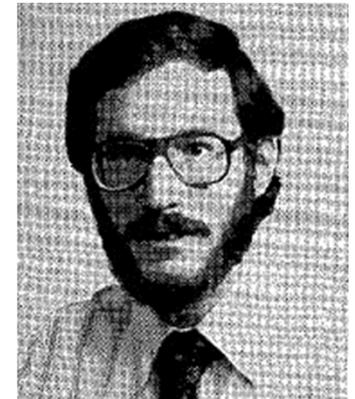
Carl Sunshine

Harry Rudin

The first PSTV conferences (i)

What was discussed ?

- 1981: Emphasis on testing (the priority of the organizer)

- 1982: several papers on temporal logic, Subgroup B FDT, Holzmann on reachability analysis tool, Sarikaya on test suite development from FSM models

- 1983: (as in previous years) various methods for protocol specification and verification, Petri nets, "Integrated Systems"

The first PSTV conferences (ii)

1984 : Skytop near New York
(Yechiam and Shaula Yemini and
Robert Strom)

1985 : Moissac near Toulouse
(Michel Diaz)

1986 : Gray Rocks near Montreal
(Gregor v. Bochmann and

Behcet Sarikaya)

Yechiam Yemini

Michel Diaz

Behcet Sarikaya

The first PSTV conferences (ii)

What was discussed ?

- 1984: several papers on using CCS or CSP, example specifications in LOTOS

- 1985 and 1986: many papers on automated implementation and verification tools for the FDT Estelle, a paper by Logrippo on an interpretive validation tool for LOTOS

In 1988, parallel conferences started:

- FORTE - "formal description techniques"
- IWPTS - "protocol test systems"

Relevance for today ?

The early work on protocol engineering, formal description techniques and related tools (described here) has been further developed within the 1980ies and '90ies, and some of the results of this work are being used today. In particular:

- **Layered protocol architecture:** The related concepts are generally accepted and used for the design of networks and distributed systems.

- **Model checking:** Today's model checking tools for distributed systems are based on the earlier reachability analysis tools which check for deadlocks and unspecified receptions; they provide in addition for checking specific properties specified in temporal logic. An example is SPIN.

Relevance for today (2)

- **UML tools:** Among the three FDTs (Estelle, LOTOS and SDL), SDL was the most successful. It was used for describing many communication protocol standards and other industrial systems, and its commercial tools have been used for the development of commercial protocol implementations, for instance in the wireless telephony sector. Recently, SDL has been integrated into UML-2 as a profile, and the tools are adapted to this new context.

- **Model-driven development:** The model-driven approach has become fashionable. Protocol engineering used this approach from the beginning. The protocol specification is an abstract model of any implementation, and protocol verification is done at the model level. In fact, the FDTs SDL and Estelle, as well as Harel's State Charts of 1987 are based on the concept of extended finite state machines from the 1970ies, and they can be considered to be ancestors of the State Diagrams notation now part of UML.

Thanks !

Questions or

Comments ??

Further readings

- copy of slides: http://www.site.uottawa.ca/~bochmann/talks/history.pdf
- paper: G. v. Bochmann, D. Rayner and C. H. West, Some notes on the history
  of protocol engineering, Computer Networks Journal, 54 (2010), pp. 3197–3209