QUALITIES OF COMMUNICATIONS PROTOCOLS AND THEIR BEARING ON ENGINEERING SUCCESSFUL SOFTWARE SYSTEMS

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2016 TECHNOLOGY TRENDS

- 8 out of the top 10 technology trends[1] directly involve or require network communications:
  - Device Mesh
  - Ambient User Experience
  - Internet of Things
  - Information of Everything
  - Autonomous Agents and Things
  - Adaptive Security Architecture
  - Adaptive System Architecture
  - Mesh App and Service Architecture
- It almost goes without saying that communications are being integrated into all kinds of applications, e.g.
  - Smart home appliances
  - Smart medical devices
  - Personal and business applications of all kinds

1 D. W. Cearly, B. Burke, M. J. Walker, *Top 10 Strategic Technology Trends for 2016*, Gartner, Feb. 29, 2016

A FEW RANDOM THOUGHTS ABOUT COMMUNICATION

Very basic communication:

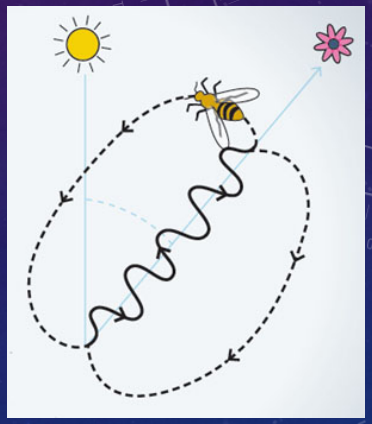
The Chicken and Egg

- Chicken squawks to broadcast that it’s laying an egg
- It communicate something about its ”state”
- However, the chicken does care if others hear her or about the state of the listeners

A FEW RANDOM THOUGHTS ABOUT COMMUNICATION

A slightly more sophisticated example of communication:

The Honey-bee Wiggle Dance

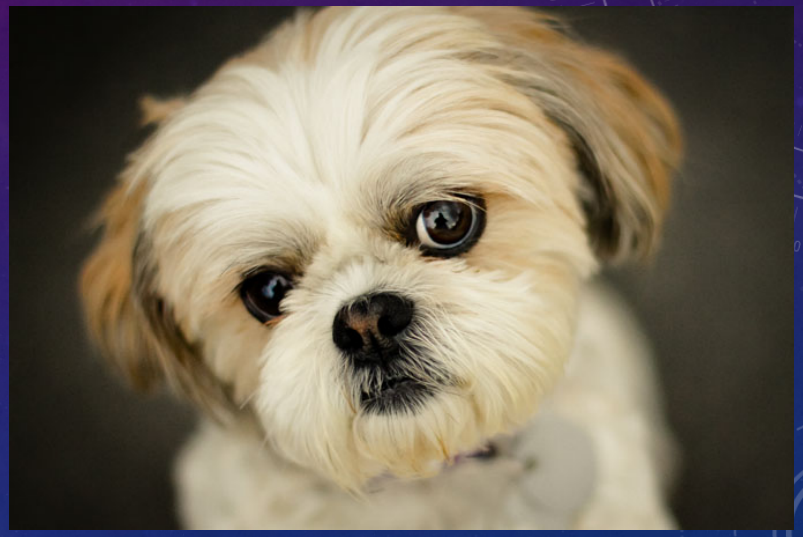


- Upon finding pollen, a scout bee returns to the hive and performs a figure-8 dance, where the orientation, length, and intensity of the wiggles communicate the location of pollen
- The dance communicates state, along with instructions for locating pollen
- The scout bee doesn't wait for a response from other bees, but competes to be heard

A FEW RANDOM THOUGHTS ABOUT COMMUNICATION

An even more sophisticated example of communication:

Zazoo's Head Pointing

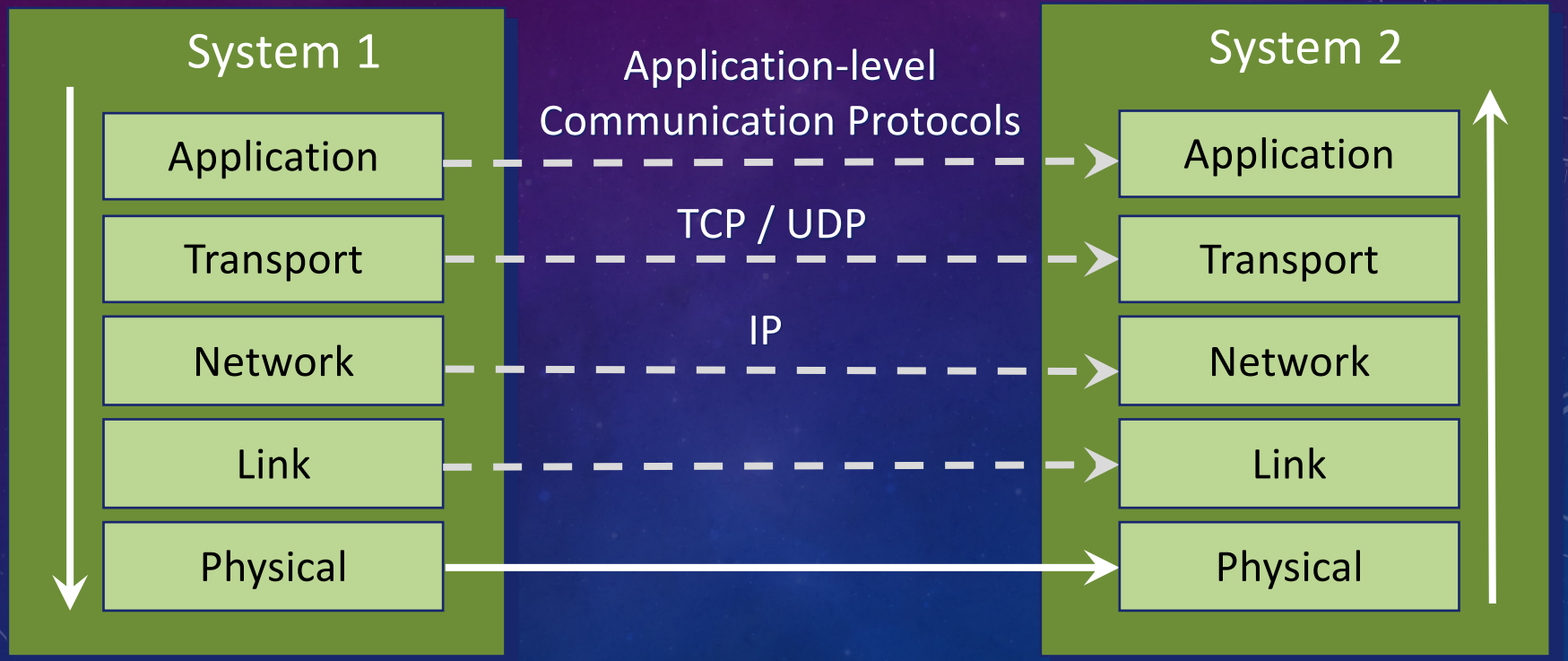


- Zazoo finds me, makes a sort of sneezing sound, points his head in the direction he wants me to go and waits for me to follow.
- He will repeat the sneezing sound and head pointing, if I don't respond
- He communications involve an exchange of state or information, with some synchronization and reliability
- It may be primitive, but there's no doubt that we have a "conversation"

CONVERSATIONS AND PROTOCOLS

- A conversation is an series of exchanges (messages) among entities (processes) for the purpose of accomplishing some task
- The messages, their sequence, format, semantics, validation, and the rules that govern the each processes expected behavior comprise a communication protocol
  - i.e., a protocol prescribes what conversations are allowed
- A set of related communications protocols is a protocol suite

LAYERS OF COMMUNICATION PROTOCOLS



APPLICATION-LEVEL COMMUNICATION PROTOCOLS (ACP'S)

- Define how the components of application software system communicate
- Can be built on top of or composed other of ACP's
- Are often unique to and custom built for an application
- Although there are many standardization efforts, certain market and technological forces exist that work against standardization
  - Competition
  - Ongoing need for incremental improvements in a product
  - Advances in technology
  - New user requirements
  - Changes in user expectations
  - Lack of awareness of appropriate standards by developers

THE PROBLEM

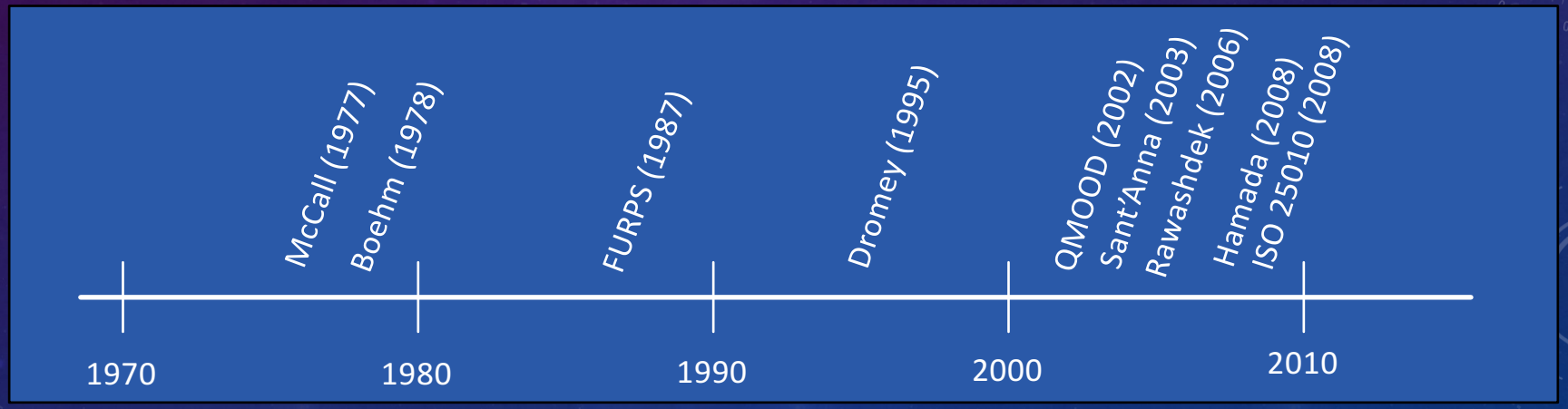
- New ACP's are being written at an accelerating rate
- The quality of ACP's seems to vary widely, e.g.,
  - Consider common file transfer tools (FTP, SFTP, SCP, file transfer portion of in RDP, etc.) They can different considerably in transfer speeds. Why?
  - Consider the Simple Mail Transfer Protocol (SMTP). Its core documentation is over 30 pages long. Simple?
  - Protocols for exchanging health information (e.g., HL7) are often hundreds of pages. Why and how does this software engineering?
- The need for good software engineers is still growing
- And, the need for training them in implementing effective network communications parallels that growth

MOVING TOWARDS A SOLUTION

- To improve the engineering of applications that have communication requirements, we need
  - More productivity in the development process
  - Ways of estimated the characteristics of the communications a system will have
  - Ways of measuring the actual characteristics of a system once it is operational
  - In other word, higher quality in communication
- But, what is “higher quality” in the context of communications?
- How can we discuss, plan for, implement, and measure such quality?
- How can we teach new developers about quality in communications?

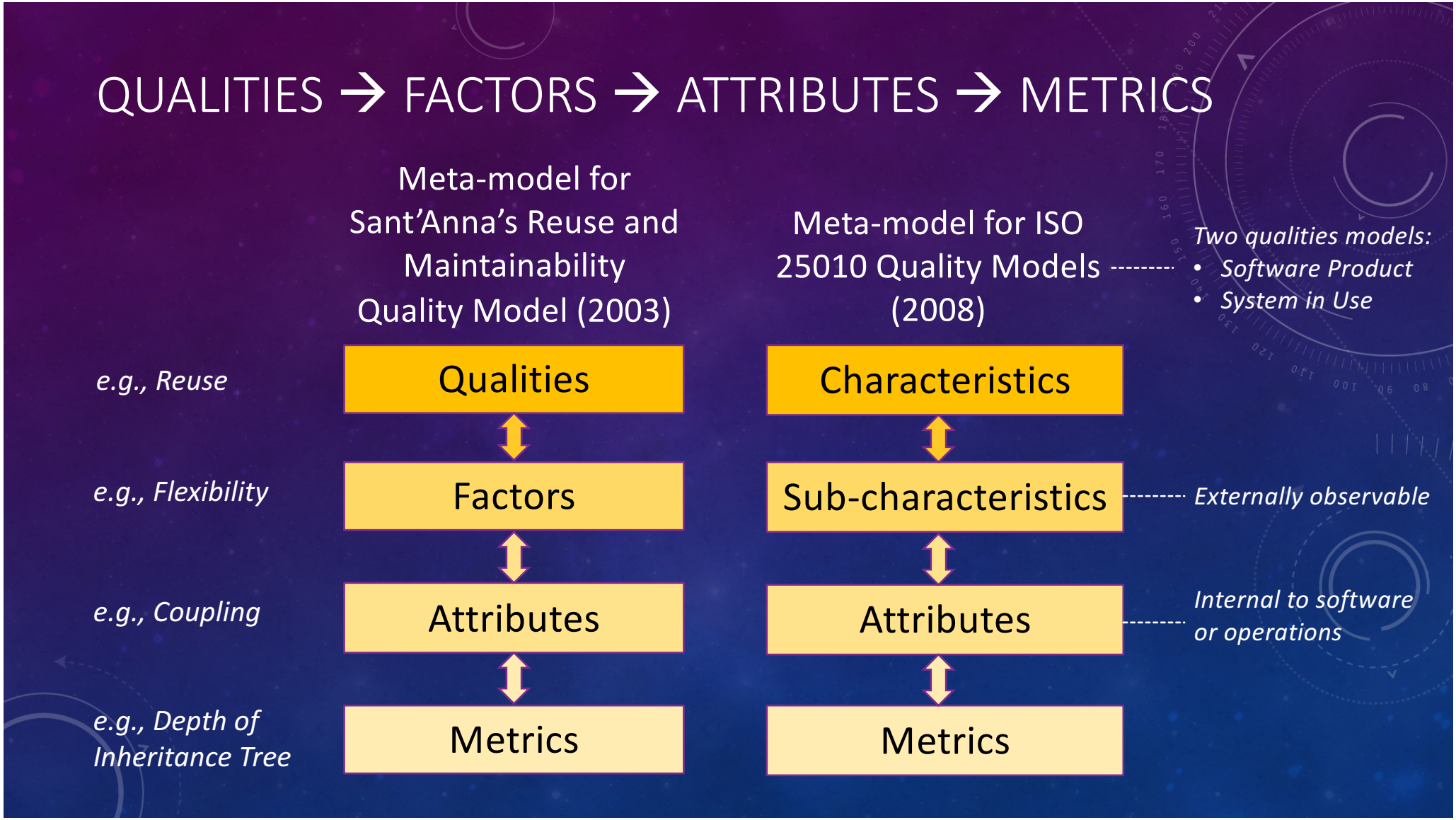
QUALITY MODELS

- Over the last 40 years, there have been many quality models proposed for software (code, software products) and operational procedures (systems in use)
  - Here are a few -- some are very general; others are specialized for certain qualities or types of software



- Over 30 quality models examined to date
- None have addressed issues unique to ACP's

QUALITIES → FACTORS → ATTRIBUTES → METRICS



QUALITY MODELS FOR ACP'S

- We adapt the meta-model of ISO 25010
  - Characteristics → general communication qualities
  - Sub-characteristics → externally observable qualities of an ACP
  - Attribute → concrete properties or conditions of the ACP that impact the sub-characteristics and that can be evaluated via metrics
  - Metrics → ways to measure the attributes
- Two quality models for ACP's
  - Idealistic Quality Model for ACP's
  - Requirements-oriented Quality Model for ACP's

IDEALISTIC QUALITY MODEL FOR ACP'S

- Includes characteristics that all ACP's should try to achieve to some degree, limited only by development resources (developers) and time
- Note that the characteristics may overlap or conflict
  - Achieving one may make it easier or harder to achieve another
- Characteristics:
  - Functional Suitability
  - Operability
  - Security
  - Performance efficiency
  - Maintainability
  - Extensibility
  - Simplicity

FUNCTIONAL SUITABILITY

The degree to which the ACP meets stated and implied needs

Sub-characteristic	Description	Attributes
Appropriately Accommodating	The degree to which the ACP allows expected conversations	• Involves appropriate participants (e.g., processes) • Authenticates participants • Includes exchanges of necessary state information at the right time • Uses appropriate messages that trigger desired behaviors in receiving processes
Appropriately Restrictive	The degree to which the ACP prohibits invalid or undesirable conversations	• Excludes inappropriate or unauthorized participants • Defines behaviors for illegal messages or message sequences
Compliance	The degree to which it uses existing standards	• Builds on or integrates existing standards (message format, encoding/decoding, establishing connections, authentication, etc.) were possible

OPERABILITY

The degree to which the ACP can be understood, learned, operate

Sub-characteristic	Description	Attributes
Recognizable	The degree to which a developer can recognize whether the ACP is appropriate for their needs	• Has a clear, complete, and update documentation • Uses standard or common terms • Uses design patterns
Learnable	The degree to which developers can learn how to implement the ACP in an application	• Has a clear, complete, and update documentation • Uses standard message formats, encoding, etc. • Uses standard or common terms
Easy to Operate	The ease of which network administrators can ensure that the conversations following this ACP can succeed	• Number and type of networks involved • Whether participants has dynamic addresses • Requires ports • Requires tunneling or VPN connections • Requires certificates and how they are distributed

SECURITY

The degree to which the ACP protects against accidental or deliberate misuse, unauthorized access, or destruction of the communicating processes, resources they manage, or network

Sub-characteristic	Description	Attributes
Authenticity	The degree to which the ACP guarantees that participants are who/what they claimed to be	• Type of authentication (e.g., certificates) • Verification (e.g., certificate authority)
Confidentiality	The degree to which the ACP guarantees that private data are not accessible to unauthorized parties	• Type of encryption of data
Integrity	The degree to which the ACP guarantees that messages are not corrupted or tampered with	• Type of encryption • Type of error detection and correction
Non-repudiation	The degree to which actions or events can be proven to have taken place, so that the events or actions cannot be repudiated later	• Uses digital signatures • Type of synchronization
Accountability	The degree to which conversations can be traced to communicating processes	• Type of addressing or identification • Type of authentication • Message provenance

PERFORMANCE EFFICIENCY

The degree to which ACP prescribes conversation that have appropriate performance, in terms of response times, turnaround times, and total throughput

Sub-characteristic	Description	Attributes
Response times	The degree to which the ACP supports conversations where communicating process quickly become aware of other state and that the conversation is proceeding	• Message-to-Message time
Turnaround times	The degree to which the ACP allows individual conversations to complete in an appropriate amount of time	• Conversation start-end time
Total throughput	The degree to which the ACP supports an appropriate number of conversations within a fixed about of time	• Completed Conversations per until of time

MAINTAINABILITY

The degree to which ACP can be modified

Sub-characteristic	Description	Attributes
Modularity	The degree to which a ACP is broken up into loosing coupling phases or sub-protocol	• Message sequence complexity • Presence and number of sub-protocols
Cohesion	The degree to which individual messages or sub-protocols are focused on a single purpose	• Unity of purpose for individual messages • Unity of purpose for sub-protocols
Reuse	The degree to which an ACP can be re-used for purposes other than the original one	• Number of uses in other applications
Testability	The degree to which an ACP can be tested	• Support for mockable process • Support for mockable messages • Deterministic

EXTENSIBILITY

The degree to which ACP can be extended

Sub-characteristic	Description	Attributes
Open message structure	The degree to which the messages (their content and structure) can be extended	• Type of messages • Message encoding • Use of standards
Open message sequence	The amount of flexibility in the acceptable message sequences	• Stateless operations • Unconstrained message sequences

SIMPLICITY

The degree to which the ACP contains no accidental complexity

Sub-characteristic	Description	Attributes
Minimal message sequences	Whether any message in the ACP can be eliminated or combined with another without compromising the functionality, reliability, synchronization	• Structure of the message sequences
Minimal message content	Whether any content of any message in the ACP be eliminated or combined with another message without compromising, reliability, or synchronization	• Message payloads

REQUIREMENTS-ORIENTED QUALITY MODEL FOR ACP'S

- The degree to which the characteristics in this model SHOULD be obtained depends on the application requirements, not on resources or time.
  - With this model, a "good" ACP is when "The ACP supports the appropriate degree of _____ for this application", where the blank is the characteristics
- Characteristics:
  - Reliability
  - Synchronicity
  - Longevity
  - Adaptability for scalable distribution
  - Resource utilization

RELIABILITY

The degree to which a communicating process can obtain an assurance that the intended receivers of some message correctly received and reacted to that message

Sub-characteristic	Description	Attributes
Detectable	The degree to which a participant in a conversation can detect successfully completed or failed conversations	• Type of message identity • Requires messages to be sent after operations, particularly state-changing operations • Requires acknowledgements shortly after message receipts • Support heart-beat or probe messages
Fault Tolerant	The degree to which ACP can allow conversation to recover from network, server, or process failures	• Allows for detection of lost messages and continuation of the conversation • Allows for detection of corrupted or altered messages and the continuation of the conversation • Allows for detection and resolution of duplicate messages • Allows for detection and resolution of out-of-order messages

SYNCHRONICITY

The amount of inter-process coordination needed in a distributed system relative to execution of actions in a distributed system

Sub-characteristic	Description	Attributes
Informed Operations	The degree to which a communicating process that need perform an action receives necessary or useful information from other processes	• Number of conversation-related operations that require information from other processes • Number of those operations are proceeded by messages with the necessary or useful information
Minimize Waiting	The degree to which a communicating process can proceed with operations related to the conversation without waiting for information from other processes	• Number of blocked-waiting-for-reply states • Expected turnaround times the message sequences that cause a process to enter and leave a blocked-waiting-for-reply states

LONGEVITY

The degree to which an ACP can support long-running conversations caused by long-running operations

Sub-characteristic	Description	Attributes
Notification	The degree to which a process can let other process know that it is beginning, working on, or ending a long-running process	• Whether the conversation triggers long-running operations and others need to be aware of their progress or completion
Awareness	The degree to a process can track the progress of a long-running operation in another process	• Whether the protocol allows long-running operations to be divided into to sequential steps or parallel tasks • Uses state messages to inform others of progress

ADAPTABILITY FOR SCALABLE DISTRIBUTION

The degree to which an ACP can support scalability distribution (increase in resource and/or number of processes)

Sub-characteristic	Description	Attributes
Resource Scalability	The degree to which the ACP allows for an increase in the number of resources	• Type of resource name resolution • Supports location transparency • Supports migration transparency • Supports replication transparency
Process Scalability	The degree to which the ACP allows for an increase in the number of processes (resource users)	• Type of process name resolution • Supports location transparency • Supports migration transparency • Supports replication transparency
Concurrent Conversation Scalability	The degree to which the ACP allows for an increase in the number of concurrent conversations	• Supports location transparency • Supports migration transparency • Supports replication transparency

RESOURCE UTILIZATION

The degree to which an ACP can utilizes available computation, data, and network resources to maximize overall system throughput and/or reduce response times.

Sub-characteristic	Description	Attributes
Load Balancing	The degree to which the ACP can support the balancing of work loads across devices and adhere to prescribed constraints on the utilization of individual computable resources	• Exchanges device load information • Allows for estimation of device loads • Supports location transparency • Supports migration transparency • Supports replication transparency
Bandwidth Balancing	The degree to which the ACP can support the reshaping of network traffic to avoid congestion and adhere to prescribed constraints on the individual or link utilization	• Supports ”quality of service” controls • Supports location transparency • Supports migration transparency • Supports replication transparency

WORK IN PROGRESS

- Continue to refine the characteristics, sub-characteristics, and attributes of each model
- Adopt, adapt, or develop metrics for the attributes
- Use the models to evaluate existing ACP’s
- Study the relationships between characteristics
- Iterate the above

IMPACT ON SOFTWARE ENGINEERING

- Without any notion of quality for ACP's, developers will be guessing or costly trail-n-error approach to creating any application that requires network communication
- With a quality model for ACP's, developers would
  - Have a basis for formalizing static metrics, which use ACP designs as input
  - Use those metrics could predicate an ACP's attributes, and in turn its sub-characteristics and characteristics
  - Be able to answer questions, like
    - Are the requirement-oriented communication characteristics a good fit
    - Are the idealistic communication characteristics achievable with the available resources and time

IMPACT ON SOFTWARE ENGINEERING

(continued)

- Be able to build design tools that help developers decide the degree to which characteristics should and aid in the design of ACP's
- Capture communication-design expertise in design patterns

- Furthermore, educators could improve curricula to better prepare student for building state-of-the-art software applications
- And, technology professional would have a basis for evaluating, comparing, and recommending software applications

FUTURE WORK

- Formally document
  - Idealistic Quality Model for ACP's
  - Requirements-oriented Quality Model ACP's
- Develop tools for
  - Guiding developers in choosing appropriate target degree of support for each characteristic
  - Capturing ACP designs in a structured form
  - Computing measurement based on the metrics
  - Estimating the attributes, sub-characteristics, characteristics of a protocol or entire protocol suite
- Design and conduct empirical studies to valid the models and metrics