
CHAPTER 7

Conclusions

This dissertation is the first evaluation of Mirage as an abstract model. We have discussed the impetus for the model and described the components of the model. Mirage has been described by its application to an existing protocol to exemplify its abstract components, and has been used to design a new protocol to illustrate components not manifested in existing protocols.

The Mirage model has been useful in refining our questions as to why existing protocols may fail in the gigabit, wide-area domain. Mirage has also presented one possible solution to the predicted failure. Further, the model was used to design a novel processor-memory interface, for which a patent has been applied.

7.1. Review

Before we elaborate on these conclusions, a review of previously presented conclusions may be useful, especially because of the conglomeration of discussions contained herein.

7.1.1. New questions

Mirage began with a discussion based on the question of whether existing protocols would ‘fail’ in gigabit, wide-area networks. We concluded that existing protocols will exhibit a performance failure in domains where information separation is high, due to their inability to accommodate variability in the communicated data stream.

Existing protocols are largely based on connection establishment and management, whereas we define the protocol as facilitating the communication of the data itself. This leads to our description of the limitation of interaction in the presence of latency, based on the limitations of the channel, and the extent to which the interaction is known to be constrained.

“What we have here is a failure to communicate” - the
Warden, in *Cool Hand Luke*

This discussion led to the formulation of the domain in which the Mirage model is applicable. This domain is based on a set of tenets, listed in Chapter 2, and repeated below.

TENET 1: Communication is logical information synchrony among information separated entities

TENET 2: A protocol is a mechanism for maintaining communication

TENET 3: Information separated entities are separated in time*space, in units of *pending-information*

TENET 4: Bandwidth-delay product is a measure of *information separation*

7.1.2. The model

The Mirage model was described in terms of transformations on state space subsets. This description led to our definitions of *stability* and *communicability*. Communicability in turn led to the development of *guarded messages* to partition the state space, and *isopotency* as the description of the way in a set of *physical* guarded messages represents a single *logical* message.

Mirage describes how error and latency are conjugates, and that the tradeoff between them is determined by the extent of existing constraints, the variance in behavior of a remote entity, the latency with which that behavior is measured, and the precision to which that behavior is modeled.

7.1.3. Existing protocols

Existing protocols were used to exemplify the components of the abstract Mirage model. Describing the model components of Mirage as they applied to NTP showed the violation of layering in the protocol, because the internal, optional algorithms were required for the description of the state space transformations and partitioning. Some of the constraint conditions were also modified as the result of this work.

Analysis of NTP also indicated that Mirage applied not only to fixed latency variable state systems, but also fixed state variable latency systems. This demonstrated the equivalence between variance in state and variance in latency.

Finally, the measurements of NTP were verified from the Mirage model by using the probability density function (pdf) interpretation of the Mirage constraint equations, where the set-notation version of the temporal transformation is expressed in terms of pdf convolutions.

7.1.4. New protocols

Mirage was also applied to a new domain, that of processor-memory interaction, to exhibit some of its components which existing protocols did not manifest. The result, μ -Net (MicroNet) showed the use of guarded messages, isopotency, and anticipation of the Mirage model. Measurements indicate that the simple branching stream model of Mirage was reasonable for a real instance of a protocol, and that an implementation of μ -Net was feasible.

Comparisons of the anticipation of μ -Net indicate that a version with as little as 400 bytes of storage can reduce the effects of latency as well as a 50K byte cache. μ -Net reduces the penalty of latency using data management, anticipation, and increased bandwidth utilization (both channel and memory bandwidth).

The application of Mirage has resulted in a novel design, for which a patent has been applied. Various levels of implementation were described, corresponding to various

partitions of the state space, as proscribed in the Mirage *communicability* and *stability* criteria.

Furthermore, existing research in anticipatory memory interfaces was extended through the application of Mirage. Finally, we developed a formula describing the speedup limitations, with respect to existing protocols (a Mirage version of Amdahl's Law).

7.2. Evaluation

The description of Mirage and the applications to which Mirage was applied were presented here in chronological order. This was an exercise in the creation of an abstract model to describe a phenomenon, although the phenomenon was expected and not observed. We predict that the performance failure of existing protocols will be due to an increase in information separation. Under this assumption, the Mirage model is an effective model, both to describe the failure and to indicate methods to avoid it.

This research differs from many other gigabit protocol analyses because it is based on initial principles of communication and interaction, rather than as an extension to existing protocol instances. Mirage shows that layering is detrimental to high speed protocols, not only on performance grounds, but because it is semantically incompatible with state space partitioning required for communicability and stability constraints.

7.2.1. And the answer is...

We began this discourse with a set of 6 questions, discussed in Chapter 1, and repeated, and addressed below.

- 1) Existing protocols show substantial drops in channel utilization in domains with high bit-latency.

The performance failure in existing protocols is due to their inability to anticipate sufficient information to occupy the round trip latency. The drop in channel utilization is the result of this inability; protocols that are able to anticipate can surpass the performance of existing protocols. The limitation of anticipation protocols is the result of an unmanageable expansion in the state of the receiver, and thus represents a constraint of the communication itself, rather than the protocol mechanism chosen.

- 2) The advantages to modeling the endpoints of the link, rather than the channel itself.

If the channel is modeled, as in Shannon's communication model [Sh63], transmission errors can be accommodated (i.e., corrected). If the endpoints are modeled (Mirage), latency can be accommodated (i.e., compensated via anticipation).

- 3) Why we conclude that the sender should anticipate the receiver.

Sender anticipation is the consequence of partitioning the state space of the sender's perception of the receiver. Communicability is possible when the partition is efficient, and when that partition is used by the sender to maintain stability.

- 4) How this results in a tradeoff between error and bit-latency.

The tradeoff between error and latency is a tradeoff between communicability and stability. If a larger state space (i.e., larger error) is considered the stable set, then more latency can be tolerated. Reduction of errors is facilitated by constriction of the stability state, corresponding to a lower bit-latency over which state expansion must be compensated.

- 5) Why achieving increased channel utilization necessitates avoiding layered protocols, i.e., why we need to look inside packets.

If the partitioning cannot be determined, latency cannot be tolerated. Layering prohibits the efficient partitioning of the state space via semantic information of the temporal transformation expansion. In effect, layering clouds the description of the expansion of the perception of a remote state; if the expansion is hidden, it cannot be predictably anticipated or managed.

- 6) There is a limit to how well we can get around things, which is a function of:

- a) variability in the receiver state
- b) bit-latency
- c) power of the sender to accommodate this variability
- d) ability of the channel to accommodate this variability

The limit to "how well we can get around things" is communicability, which is a measure of the extent to which stability can be maintained. Communicability decreases with bit-latency increases or with increases in receiver variance, because either permits the perception of the remote state to expand more rapidly. The power of sender accommodation is determined by the degree to which an efficient partition of this

perception can be determined. Channel accommodation is determined by bandwidth, in its ability to transfer the entire isopotential set in the latency given.

7.2.2. Is Mirage useful?

Mirage provides a model for understanding the effects of latency on communication. It differs substantially from existing models, and was useful both in the description of an existing protocol and in the design of a new protocol. Mirage reduces to conventional models where information separation approaches zero, because it is an extension of finite state models into a state space subset model.

“It is better to debate a question
without settling it
than to settle a question
without debating it.”

- Joseph Joubert, 1754-1824,
in *In Search of Schrödinger's Cat [Gr84]*

The most important result of this work is the questions that were asked. Mirage is a model in which the effects of latency can be considered, and in which performance failures of existing protocols can be considered. Issues of layering, stability, and the limitation of communication in the presence of high bandwidth-delay products can be discussed through the use of the Mirage model.

7.3. Future Directions

This dissertation presented the Mirage model, and provided some examples of its use in protocol analysis and design. The model can be further developed as an abstract medium for protocol science. Mirage can also be applied to other protocols, to analyze their effectiveness or examine their limitations in the presence of latency. The protocol developed as part of this research, μ -Net, can also be further investigated, and an implementation developed.

7.3.1. Abstract studies

Mirage was described as an abstract model for latency. The Mirage model concept transcends the actual model description; it is the incorporation of imprecision and temporal constraints to existing models. The description in this dissertation was presented as an extension to existing finite state machine models (and elaborated in Appendix E), but can be described in terms of other existing models as well. One such example uses Petri Nets as the corresponding existing model (Appendix F). The Mirage model can also be interpreted as an extension of Shannon's communication model, as a temporal extension to that work. Preliminary description of this interpretation appears in Appendix A.

Mirage was developed by applying intuition from analogs in physics, notably particle interactions, to communication issues. The correlation between Mirage and physics may also be of more formal interest. A discussion of some analogs used in the development of the model appears in Appendix B.

The TreeStack is another abstract component of Mirage which may have more general application. Further investigation of this data structure, and whether it exists or is useful in other domains, may prove useful.

7.3.2. Protocol studies (analysis)

Mirage can be used to analyze protocols that are more intricate than NTP. Current protocol research is focusing on issues of flow control, both anticipatory and reactive. Application of Mirage to flow protocols may assist in this analysis.

7.3.3. Implementation studies (design)

Mirage can also be used to design other new protocols, as it was used herein to develop μ -Net. Future work on μ -Net includes emulation to measure the feasibility of a Total anticipatory design, to determine the space requirements for a given latency. An implementation of μ -Net, either in software or directly in hardware, would also be useful in further analysis of the benefits of this protocol.

CHAPTER 8

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