A GLIMPSE OF THE FUTURE: THE 62ND PTTI SYSTEMS & APPLICATIONS MEETING NOVEMBER 2030

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Abstract

If the PTTI Systems & Applications Meeting is to thrive and grow, our community needs to consider the direction this conference should take as the 21st century proceeds. At a conference workshop, attendees attempted to assess our community's optimal appearance 20 years from now, and to develop plans to put the PTTI conference on a path to that future. Here, we review the major ideas brought up at the workshop. Specifically, after a brief review of some of the topics that have been of interest to the PTTI community over the past 20 years, attendees were asked to break into groups and brainstorm various views of a PTTI future. The task of these groups was threefold: 1) to predict the session and paper titles for the 62nd Annual PTTI Meeting – to be held in November 2030, 2) to list the impediments that could thwart realization of that conference, and 3) to imagine mitigation strategies that could remove those impediments. Junior and senior members of each group volunteered to further explore these ideas, and to present their thoughts/findings at next year's PTTI conference.

INTRODUCTION

FORECASTING

Though seeing into the future is difficult, some people have been able to forecast tomorrow's technology with amazing accuracy. Jules Verne wrote about manned flight to the moon from a launch base in Florida in 1865 **[1]**, and Arthur C. Clarke described the use of communications satellites in geosynchronous orbit for worldwide communications in 1945 **[2]**. Most people in the technical communities are aware of Moore's law, originally written in 1965, which states that "[T]he complexity for minimum component costs has increased at a rate of roughly a factor of two per year" **[3]**; and Tom O'Brian of NIST has stated a variation of Moore's law for the time and frequency community: "[T]hey [*clocks*] improve by a factor of 10 every decade" **[4]**. Of course, there are also examples of bad predictions. A Western Union internal memo from 1876 stated that "[T]his telephone has too many shortcomings to be seriously considered as a means of communication. … The device is inherently of no value to us" **[5]**. Additionally, at the World Future Society in Boston in 1977, Ken Olson (President of Digital Equipment Corporation) said that "there is no reason for any individual to have a computer in their home" **[5]**. With these examples in mind, the workshop attendees attempted to see PTTI in 2030.

GRADUAL EVOLUTION VS. PUNCTUATED EQUILIBRIUM

Evolution as a smooth and continuous process (called phyletic gradualism) is a theory that postulates that evolution or technical progress is gradual. It states that every generation is very closely related to the previous generation, and that very small changes in each generation may take many (thousands) of generations to create a new species. In contrast, punctuated equilibrium is a theory in which an extended period of steady-state is followed by burst-like change, and then followed by another period of extended steady state **[6]**. Though typically employed in evolutionary biology, punctuated equilibrium has been expanded to many other areas, including economics, social theory, and seismic shifts. With regard to our own community, the realization of the piezoelectric effect and the development of the transistor are two examples of punctuated equilibrium; and such examples from technological development have caused Apple's Bruce Toganizzi to state that "[S]uccessful technology-predicting is based on detecting discontinuities and predicting the trends that will flow from them" **[4]**. Prior to breaking into groups, the attendees were sensitized to the fact that technical innovation may take either path into the future.

FINANCING TECHNOLOGY

Technology development is usually not free and thought must be given to the funding of new technology. Niven **[7]** has two rules for predicting a valid future technology and both rules have a fiduciary component:

1. Look for the goals humankind will never give up. Instant travel, instant education, longevity. Then try to guess when it will appear and what it will look like. Pay close attention to parasite control. There is always someone who wants the money for something else.

2. You're obliged to predict, not just the automobile, but the traffic jam and the stranglehold on gas prices. Nobody invents anything unless there is at least the illusion of a profit.

Similarly, Robert J. Sawyer implied that future developments depend on the market when he said:

> The trap we science and space buffs always fall into is thinking that everybody will want the things that we want… They don't; they have their own agendas, and ultimately, as in everything, it's the economy, stupid. Just because you personally want something doesn't mean there's a market for it. Just because we technically could do something doesn't mean that's how others want to see their tax dollars spent. **[7]**

In attempting to predict where our community would be in 20 years, the workshop attendees were asked to keep financial considerations in mind.

DELPHI METHOD

Technical forecasting often employs the Delphi method, relying on a group of experts, and was originally developed by Dalkey and Helmer around 1953 **[8]**. The method has a series of rounds where the experts are asked to respond to a question, and sometimes justify their answer. The answers from each round are aggregated with statistical scoring, and in subsequent rounds the experts are shown the results of the previous round and asked to refine their forecasts.

The rounds are usually done anonymously, because face-to-face meetings are subject to problems: group-think, personality conflicts, dominating individuals, confrontations, defensiveness, and pride (i.e., experts

refusing to change their mind) **[8,9]**. One of the originators of the Delphi Method, Norman Dalkey, stated that the Delphi Method has "three features: 1) Anonymous response … 2) Iteration and controlled feedback [and] … 3) Statistical group response" **[10**, p. v**]**. As discussed in the next section, our workshop employed a variant of the Delphi Method.

PTTI 30 YEARS AGO

The annual PTTI Meeting has seen significant evolution in the 41 years of its existence. There are many examples of gradual evolution (position accuracy as GPS satellites increased from 18 to 24 to 30) and punctuated equilibrium (centimeter-level positioning accuracy when carrier-phase measurements were developed). Table 1 shows the titles of the sessions 30 years ago **[11]** and this year **[12]**.

Table 1. PTTI session titles in 1979 and 2009.

1979	2009
PTTI Requirements, Applications & Plans	Time from GNSS
Outlook on New Technology	Time Transfer Techniques
Dissemination Systems	Algorithms
Recent Advances	Poster Session
Synchronization Systems	National Lab Update
	Calibration: Receivers & Systems
	Time Transfer – Data Treatments
	Space Clocks
	Advanced Clocks
	Receiver Biases

PROCESS USED

Though our PTTI forecasting experiment did not conform to the true Delphi Method, since the responses in Round 2 were not anonymous, it nonetheless employed many of the same ideas (i.e., experts, rounds, aggregation of results). The present method is flowcharted in Fig. 1. Briefly, in Round 1 the present authors (LM and JC) e-mailed an open-ended question to a number of "experts" asking them to identify PTTI 2030 topic areas. In Round 2, workshop attendees broke into groups focused on the broad-area topics, and were asked to "flesh out" the topic areas. Attendees were asked to consider what the 2030 conference papers might discuss for that topic area, and what the impediments might be in terms of realizing such a 2030 conference paper.

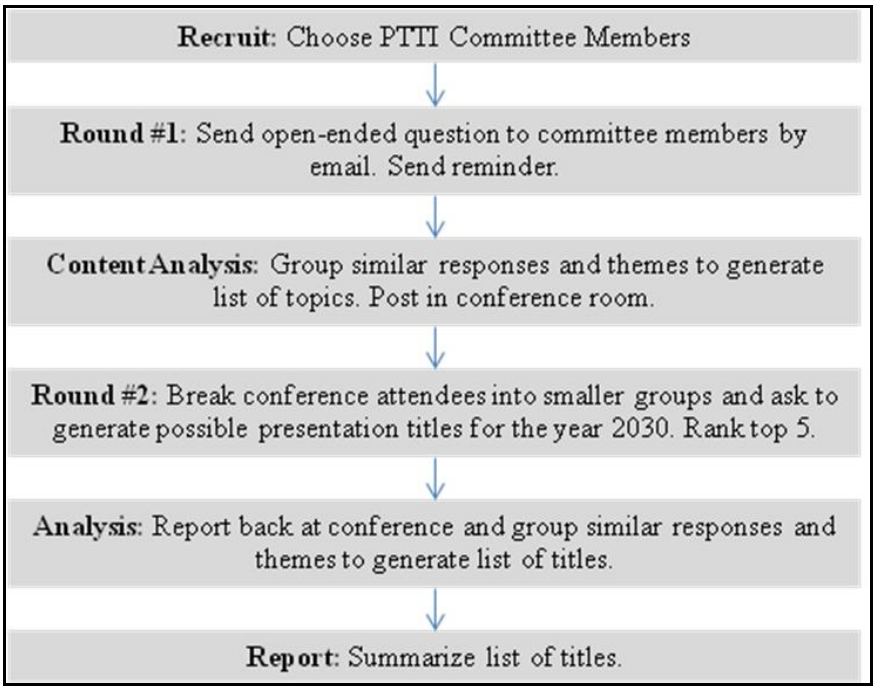

Figure 1. Flow of the present work's variation of the Delphi Method. Adapted from **[15]**.

ROUND #1

Participants for Round 1 were chosen on the basis of their expertise and interest in PTTI: the members of the 2009 PTTI Executive Committee, the Advisory Board, and session chairpersons. These experts were shown the session titles from Table 1, and asked to answer a survey question by e-mail in August 2009. A reminder e-mail was sent in September 2009. The survey question was:

Please list possible PTTI session topics/titles that will be used in 20 years (2030).

The responses were aggregated, quantities of responses were calculated, and both are provided in Table 2. The list of all the titles was handed out at the workshop, and is included in the Appendix.

Table 2. Potential PTTI session titles in 2030.

Potential 2030 Sessions	Statistics
1. Systems Applications of Advanced Clocks	26.2%
2. Out-of-the-box PTTI Applications	16.7%
3. Time Transfer and Applications	14.3%
4. How Should the PTTI Conference Contribute to Time Scales	11.9%
5. (Tele)Communication Systems Applications of PTTI	11.9%
6. Green Systems and Precise Time	9.5%
7. Relativity in Everyday Systems	9.5%

ROUND #2

Attendees at the workshop, which was open to all conference attendees, were asked to break into smaller groups and participate in face-to-face discussions. The Round 2 population was approximately 40 people, and included less than half the experts from Round 1. The following rules/procedures were employed:

- Whiteboards with pre-written session titles were placed around the room.
- Copies of Round 1 responses were made available near the whiteboards.
- Participants were asked to go to the whiteboard for the topic of their interest.
- Participants were asked to introduce themselves by name, field, position, and number of years in their field.
- The least senior person in the group was asked to act as the group's note taker.
- As a group, participants were asked to identify possible PTTI presentation titles that will be used in 20 years (2030 PTTI).
- There was a 40-minute discussion period.
- There was a 5-minute warning to give discussants time to organize their thinking and identify the most salient points (e.g., most important titles).
- When the 5-minute warning was up, groups were asked to report back orally to the entire workshop with the note taker reporting back for the group.

RESULTS

SESSION 1

Systems Applications of Advanced Clocks – This group was composed of approximately five individuals, with Ryan Dupuis acting as note taker. The group presented the following 2030 PTTI paper topics to the workshop:

1. Autonomous vehicle navigation based on localized beacons utilizing miniature clocks with nanosecond stability and ultra-low power (less than 10 mW)
2. Self-calibrating scientific instruments through the use of cost-efficient and stable atomic clocks
3. Replacement of cell-phone back-haul timing via local timing with internal ultra-stable miniature clocks
4. Moon-based VLBI using high precision clocks.

SESSION 2

Out-of-the-box PTTI Applications – This was a group of approximately seven individuals, and Paul Kunz acted as the note taker. The group presented the following 2030 PTTI topics to the workshop:

1. Redefinition of time scales in terms of fundamental (Grand Unified Theory) physics
1. Precise timekeeping applications in chemistry and biology
2. Global monitoring with precise time: Historical climate change, Earth rotation rate, and hazardous weather warning
3. Generation of a self-aware time scale.

SESSION 3

Time Transfer and Applications – This group consisted of approximately eight individuals, with Stephen Mitchell as note taker. The group presented the following 2030 PTTI topics to the workshop:

1. Applications of Internet/GPS-III nanosecond-level time transfer
2. Progress on wireless 1588
3. How all-optical networks have revolutionized time transfer
4. Advantages of a 1588-based power grid
5. Results from real-time distribution of UTC (BIPM).

SESSION 4

How Should the PTTI Conference Contribute to Time Scales – This was a group of approximately eight individuals, and Pawel Nogas acted as note taker. The group presented the following 2030 topics to the workshop:

1. BIPM lab report of (near) real-time realization of UTC.
2. 10 years of UTC without leap seconds
3. Redefinition of the second
4. Realization of UTC within the solar system.

SESSION 5

Telecommunication Systems Applications of PTTI – This group had no individuals. However, during the report back Wolfgang Schaefer (from Session 2) agreed to represent this topic in future discussions, and the following 2030 topic was suggested.

1. Time transfer in interplanetary communications.

SESSION 6

Green Systems and Precise Time – This was a group of approximately six individuals, and Bill Cashin presented the following 2030 topics to the workshop:

1. Deep space navigation/communications: The next frontier
2. Cleaning toxic spills – one molecule at a time
3. Actual visual of Aunt Ida's gall stone without surgery – next-generation MRI.
4. Automated mass transit – guidance remotely
5. Eliminate the middle man – surgery without doctors
6. Star Trek transporter – a reality for clean travel.

SESSION 7

Relativity in Everyday Systems – This group was composed of approximately four individuals, with Aaron Dahlen acting as note taker. The group presented the following 2030 topics to the workshop:

1. Special relativity and time tagging in financial transactions – 20 ns/day clock errors and Wall Street
2. Need for high precision relativity corrections in GNSS

3. Water table and air pressure effects influencing $\Delta f/f$ at the 10^{-18} level via General Relativity
4. Redefining UTC at the barycenter.

CONCLUSIONS

Overall, the workshop on the 20-year future of PTTI (i.e., forecasting the 2030 PTTI conference), was a useful exercise. A number of future PTTI topic areas were outlined, and delineated with hypothetical paper titles. As part of the workshop, each group's note taker "volunteered" to work with a more senior member of the group, and over the course of the coming year better outline the path to achieving the group's vision. Workshop conferees agreed that this would entail identifying other professional groups that the PTTI organizers might want to bring into the PTTI conference (e.g., biological/medical researchers involved with timekeeping), identifying experts in diverse fields aligned with PTTI who might help make the group's vision of the future more readily realized (e.g., mass transit experts or computer trading experts), and identifying impediments to the group's vision of a 2030 PTTI conference (e.g., at what level is GNSS good enough?). Each of the note takers along with their senior colleague agreed to present a poster at next year's PTTI discussing the results of their considerations:

Systems Applications of Advanced Clocks – Ryan Dupuis and Bryan Owings

Out-of-the-box PTTI Applications – Paul Kunz and Stefania Romisch

Time Transfer and Applications – Stephen Mitchell and James Wright

How Should PTTI Conference Contribute to Time Scales – Pawel Nogas and Włodzimierz Lewandowski

Telecommunication Systems Applications of PTTI – Wolfgang Schaefer

Green Systems and Precise Time – William Cashin and Qinghua Wang

Relativity in Everyday Systems – Aaron Dahlen.

REFERENCES

[1] J. Verne, 1865, **From the Earth to the Moon (*De la terre à la lune*)** (Pierre-Jules Hetzel).

[2] A. C. Clarke, *"Extra-Terrestrial Relays – Can Rocket Stations Give Worldwide Radio Coverage?"* **Wireless World**, October 1945, pp. 305-308.

[3] G. E. Moore, 1965, *"Cramming more components onto integrated circuits,"* **Electronics, 38,** No. 8, 114-117.

[4] T. O'Brian, quoted in Q. Norton, *"How Super-Precise Atomic Clocks Will Change the World in a Decade,"* **Wired**, 12 December 2007 (*www.wired.com*).

[5] D. Chaffey, *"Predicting the future of technology – classic quotations,"* retrieved from *www.davechaffey.com/E-business/C4-E-environment/predicting-the-future-of-technology-classic-quotations*, 27 September 2008.

[6] N. Eldredge and S. Gould, 1972, *"Punctuated equilibria: an alternative to phyletic gradualism,"* in **Models in Paleobiology** (ed. T. J. M. Schopf; Freeman Cooper & Co, San Francisco), pp. 82-115.

[7] **D.** Dern, D., *"What Science Fiction Writers Have Learned About Predicting The Future of Technology,"* retrieved from *www.cio.com/article/471261/What_Science_Fiction_Writers_Have_ Learned_About_Predicting_The_Future_of_Technology*, 16 December 2008.

[8] N. Dalkey and O. Helmer, 1963, *"An experimental application of the Delphi Method to the use of experts,"* **Management Science, 9,** No. 3, 458-467.

[9] H. Linstone and M. Turoff, 2002, **The Delphi Method: Techniques and Applications** (Addison-Wesley, Reading, Massachusetts).

[10] N. Dalkey, *"The Delphi Method: An experimental study of group opinion,"* RAND Corporation Report RM5888-PR, June 1969.

[11] 1979 PTTI Meeting Final Program.

[12] 2009 PTTI Meeting Final Program.

[13] S. McKitrick, 2007, *"Assessing 'ineffable' general education outcomes using the Delphi approach,"* paper presented at the 2007 North Carolina State Undergraduate Assessment Symposium, Cary, North Carolina, USA.

APPENDIX: RESULTS OF ROUND #1

1. Systems Applications of Advanced Clocks

- Clocks on a chip
- Clock researchers looking for clocks with time keeping capabilities of 1 ps over 10 days (or 1 ns over 10 years)
- RbSXO (Rubidium Sapphire Oscillator) – sub-femtosecond stability from $\tau = 1$ to 10^6 seconds
- Miniature low-power Hg^+ standard in cell phones and GPS receivers
- PuU (pronounced pew) Plutonium Uranium frequency standard achieving attosecond stability despite radiation concerns
- Cold atom and laser clocks become production items at $\Delta f/f_o \sim 10^{-17}$
- Crystal oscillators as we know them replaced by nanotechnology and small atomic clocks
- Clocks on a molecule.

2. Out-of-the-box PTTI Applications

- The SI second as realized by optical resonances
- Paleochronology
- Time experiments planned for the 2061 intercept of Halley's Comet
- Farmers using GPS and precise time to plant their fields accurately, even in the dark.
- Synchronizing chemical processes
- Clock modeling
- From nanotubes to nanocrystals – the perfect crystal oscillator.

3. Time Transfer and Applications

- Attosecond (10^{-18} s) time transfer
- Attosecond PTTI applications
- 1588 and its descendants providing sub-nanosecond time transfer over intercontinental distances.

4. How Should the PTTI Conference Contribute to Time Scales

- The future of UTC
- Space vs. ground time & geodetic references for navigation
- Real time and high accuracy time scales
- Time scales to replace UTC and TAI.

5. (Tele)Communication Systems Applications of PTTI

- Ultra advanced "spread spectrum" communications and modulation schemes
- Fast detection of clock anomalies
- GPS and GPS-like systems in the future
- The future of timing for telecom networks: 10^{-11} or 10^{-20} in 2030 – or are we all switching to NTP?

6. Green Systems and Precise Time

- Going green with precise time
- Femtosecond GPS accuracy eliminating manual driving, making our roadways safer
- PNT devices integrated into just about everything for high-speed connectivity/tracking.

7. Relativity in Everyday Systems

- Precise time in the vicinity of black holes
- Clock synchronization limited by relativity
- Financial systems and relativity.