SEL0: A FAST PROTOTYPE BULLETIN PRODUCTION PIPELINE AT THE CTBTO

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ABSTRACT

The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is exploring and assessing which data and products, beyond the raw waveform data from the International Monitoring System (IMS), might be useful and can be provided by the CTBTO's Provisional Technical Secretariat (PTS) as input to tsunami warning centers. One of the critical features of such input is the timeliness of the delivery. The earliest standard automatic network processing at the International Data Centre (IDC), standard event list 1, or SEL1, forms events 1 hour and 40 minutes after they occur. This is too late for consideration by a tsunami warning system. Starting in February 2005, the PTS has conducted a technical test in its IDC development environment where the standard IDC software was tuned and improved to minimize the time difference between occurrence of the event and writing into a new standard event list in the database. This new standard event list is called SEL0. Time differences on the order of 20 minutes are routinely achieved between event occurrence and the writing of an event into the database, which should make it a usable input to an organization tasked with generating a tsunami warning. We present the basic characteristics of the configuration of this new processing pipeline, some statistics on the results achieved with this prototype, and future work to be conducted under this project. The basic conclusions are that, under stable conditions, no large events of interest are missed by the SEL0 pipeline and that the false alarm rate has shown some improvement during the last year of development of the pipeline.

OBJECTIVES

The objectives of this project are to develop a prototype processing pipeline using the IMS network that can produce a timely bulletin useful as input for agencies charged with warning the general public about impending disasters such as tsunamis.

Specifically, the elements of interest in a bulletin for such an agency would be as follows:

- Timeliness of the bulletin. This is the most critical element of the prototype system, as the warning has to be issued as early as possible to allow sufficient time for civil authorities to proceed with such actions as evacuation. We set this objective at an indicative time of 20 minutes after the occurrence of the event, given that the IMS network is not sufficiently dense to provide a faster bulletin uniformly on the surface of the globe.

- Minimal missed event rate. This is another critical element of the prototype system, as missing a large event would be unacceptable. There are several stages in an operational system that would be prone to failure leading to missed events. This includes failures of the acquisition system, hardware failures, database problems, or failures of the software system to detect a large event. At this stage of the prototype, since we have operated using minimal resources and in a development environment (where interruptions to processing are not uncommon), we have concentrated on the ability of the software to detect the large events when the acquisition and the hardware environment were stable.

- Location accuracy of the bulletin. This is an important element in determining whether the event is offshore or close to the shore and thus has the potential to generate a tsunami.

- Minimal false alarm rate. This is important in order to minimize disruption in the overall warning mechanism (it is important to remember that civil actions, such as evacuations ordered as a result of a tsunami warning, are themselves not without risk and often result in injuries or event deaths.)

- Accurate sizing and focal mechanism for events in the bulletin. The IDC automatic bulletins produce a measure of the size of the event based on the *mb* magnitude. It is well known that this magnitude scale saturates for events larger than about 6.5 (e.g., Abe, K, 1995). It is therefore important to develop other methods of assessing the size of large events in a timely manner. We have investigated the possibility of performing moment tensor inversion on long period P waves. This is currently at the development stage. The focal mechanism would also provide additional information for the tsunamigenic potential of the event.

RESEARCH ACCOMPLISHED

Configuration of the SEL0 Pipeline

The software used to produce the SEL0 bulletin is identical to the standard IDC software. The difference is that processing includes an additional set of auxiliary seismic stations received continuously in addition to the IMS primary stations. The configuration of the software is the main difference with the standard IDC processing. The main adjustments to data processing are that station processing intervals are 2 minutes instead of 10 minutes long in standard IDC processing, and network processing is run every 5 minutes instead of every 20 minutes in standard processing. The timing of network processing is also moved from 1 hour and 40 minutes to 20 minutes after the time of the event. An additional feature of SEL0, compared with the standard IDC processing, is that it keeps track of all instances of events written to the database as soon as they are written to the origin database table. To achieve this, in addition to the standard ORIGIN table, the ORIGIN_EWS table contains all versions of events and may contain the same event several times.

SEL0 processing is currently done in a non-operational context, on the IDC development environment, using a mixed Solaris-Linux environment, where most of the heavy-duty processing is done under Linux (detection processing, phase identification, and network processing.) This non-operational mode implies that processing stops when forwarding of data is interrupted. To ensure timeliness of results, the SEL0 pipeline is configured to ignore data arriving more than 30 minutes after real time. This is in contrast to the normal IDC Operations where "catch up" after an extended outage significantly delays automatic bulletin production. Maintaining a constant data flow to the SEL0 pipeline would be a high priority if it were to become operational. In the current context, events are missed when the data are late or interrupted, which is not acceptable for an operational system.

Reporting on a Monitoring Web Page

Figure 1 shows the web interface through which detailed information about events generated by the SEL0 pipeline can be accessed. The page is continually updated by the processing to display the most recent events built by the processing. The final column of the figure shows the delay in minutes between the origin time of the event and the time at which it was written to the database.

#	Origin Time (hum)	Origin Time (ep)	Orid	Latitude	Longitude	Depth	Magnitude	Nass	Ndef	Region	Delay(m)
1	2006-07-04 03:56:32	1151985392.4	227315	42.8499	114.6850	0.0	4.5	9	6	NORTHEASTERN CHINA	23.62
2	2006-07-04 03:56:25	1151985385.5	227313	39.1289	116.1712	0.0	4.6	39	14	NORTHEASTERN CHINA	18.75
3	2006-07-03 16:33:36	1151944416.1	227152	-6.6526	129.1601	41.4	4.6	13	6	BANDA SEA	21.67
4	2006-07-03 13:39:51	1151933991.8	227099	-20.3941	-176.1112	123.0	4.8	26	8	FIJI ISLANDS REGION	15.43
5	2006-07-03 08:05:45	1151913945.0	227004	-40.8960	-72.4163	0.0	4.7	3	3	CENTRAL CHILE	19.42
6	2006-07-03 04:22:10	1151900530.9	226954	-15.1054	-177.5331	0.0	4.6	8	5	FIJI ISLANDS REGION	18.00
7	2006-07-03 04:12:37	1151899957.6	226950	-10.3630	-177.3580	0.0	4.5	6	4	NORTH OF FIJI ISLANDS	17.60
8	2006-07-02 17:20:28	1151860828.1	226788	55.2614	178.9313	0.0	4.7	9	6	BERING SEA	24.85
9	2006-07-02 17:20:34	1151860834.8	226786	51.0903	-179.4801	132.4	4.6	37	13	ANDREANOF ISLANDS, ALEUTIAN IS.	19.57
10	2006-07-02 16:57:06	1151859426.5	226776	42.4556	-170.5177	0.0	4.5	10	4	NORTH PACIFIC OCEAN	23.05
11	2006-07-02 16:58:10	1151859490.9	226774	51.0166	-179.3487	151.4	4.6	26	8	ANDREANOF ISLANDS, ALEUTIAN IS.	17.02

Figure 1. Example of a web page on July 3, 2006, showing the most recent SEL0 events at that date with mb magnitude larger than 4.5.

Events with M_w > 6 for Test Periods between June 7 and June 21, 2005, and between June 14 and June 30, 2006

The events of interest for a warning system are large events. Our testing has concentrated on events with M_w larger than 6.0 as reported in the Preliminary Determination of Epicenters (PDE) bulletin of the U.S. Geological Survey (USGS). During the 15 days between June 7 and 21, 2005, processing was relatively stable, with the exception of 13.5 hours between 02:30 and 16:00 on June 13, 2005, caused by a hardware failure. Similarly, during the period between June 14 and 30, 2006, processing was stable with the exception of a slowdown on June 27 between 18:00 and 19:00. Table 1 shows the 15 events published in the PDE (USGS) catalog with M_w magnitude larger than 6.0 during these time intervals. Note that one of them, event 3, grayed in the table, falls in the SEL0 processing gap previously mentioned, whereas event 15 could not be obtained because data acquisition was delayed by more than 30 minutes. Event 6, offshore California, prompted a tsunami warning (issued, but subsequently cancelled) and resulted in maximum wave heights (peak-to-trough) of between 26.0 cm at Crescent City down to 2.0 cm at Bamfield, Vancouver Island, Canada.

Table 2 shows the SEL0 events corresponding to the PDE events during the two time periods. The last column in the table shows the delay time between the origin time of the event and the time at which the event was written to the database. Note that all the events were formed in the SEL0 bulletin at the exception of events 3 and 15, when the SEL0 processing was disrupted.

Table 1. PDE events with M_w > 6.0 from June 7 to 21, 2005, and from June 14 to 30, 2006 (see Figure 2). The grayed events fall in a processing gap due to hardware failure or late processing

Event number	Latitude	Longitude	Depth (km)	USGS M_w	Date	Time
1	2.21	96.74	46	6.1	08-Jun-2005	06:28:13.90
2	-56.24	-27.04	94	6.0	12-Jun-2005	19:26:24.81
3	2.09	126.61	10	6.0	13-Jun-2005	07:02:33.11
4	-19.93	-69.03	117	7.8	13-Jun-2005	22:44:33.86
5	51.23	179.39	51	6.8	14-Jun-2005	17:10:16.35
6	41.28	-125.98	10	7.2	15-Jun-2005	02:50:53.01
7	-4.59	153.19	75	6.3	15-Jun-2005	10:13:59.10
8	-44.97	-80.57	10	6.5	15-Jun-2005	19:52:24.31
9	40.76	-126.60	10	6.7	17-Jun-2005	06:21:41.92
10	51.78	177.07	14	6.4	14-Jun-2006	04:18:42.44
11	45.41	149.35	95	6.0	22-Jun-2006	10:53:11.63
12	-0.44	123.30	53	6.3	24-Jun-2006	21:15:04.94
13	52.24	176.23	37	6.2	27-Jun-2006	02:39:36.02
14	-19.87	-178.31	571	6.2	27-Jun-2006	02:59:15.72
15	6.53	92.72	32	6.2	27-Jun-2006	18:07:23.05

Table 2. SEL0 events matching PDE with M_w > 6.0 from June 7 to 21, 2005, and from June 14 to 30, 2006 (see Figure 2)

Matching PDE Event	Latitude	Longitude	Depth (km)	IDC mb	Date	Time	Delay time (min.)
1	2.21	96.79	67	5.07	08-Jun-2005	06:28:16	17.7
2	-56.34	-27.19	55	5.22	12-Jun-2005	19:26:22	19.4
4	-18.83	-71.74	0	6.66	13-Jun-2005	22:44:26	21.6
5	51.31	179.48	99	5.51	14-Jun-2005	17:10:22	20.2
6	41.67	-125.51	0	5.03	15-Jun-2005	02:50:54	26.5
7	-4.60	152.91	96	5.48	15-Jun-2005	10:14:02	17.4
8	-44.89	-80.75	0	4.89	15-Jun-2005	19:52:23	18.9
9	40.91	-126.27	19	5.46	17-Jun-2005	06:21:44	18.8
10	51.76	177.21	0	5.05	14-Jun-2006	04:18:40	16.6
11	45.45	149.21	73	5.61	22-Jun-2006	10:53:09	17.0
12	-0.28	123.31	0	5.37	24-Jun-2006	21:14:56	20.2
13	52.06	176.19	112	4.74	27-Jun-2006	02:39:43	15.5
14	-19.77	-178.25	556	5.04	27-Jun-2006	02:59:15	15.9

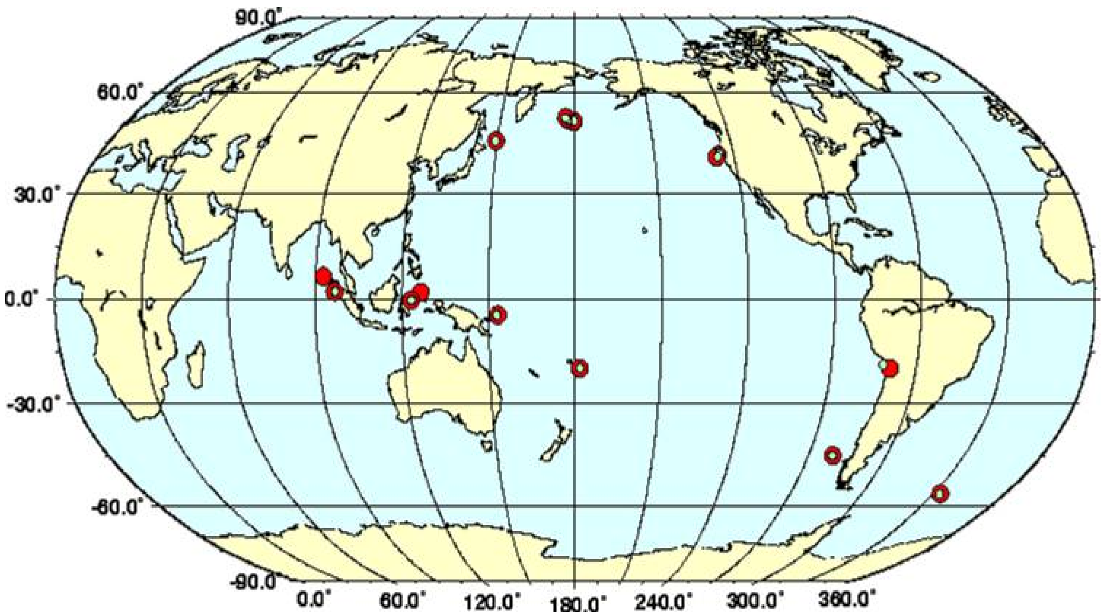

Figure 2. This map shows the 15 PDE events (in red) with Mw >6 during the time period between June 7 and 21, 2005, and between June 14 and 30, 2006. The matching SEL0 events are shown in green. Owing to a hardware failure, the SEL0 processing could not process the time period including the Molucca Sea event. Similarly, due to late processing, one Indonesian event on June 27, 2006, was not obtained by SEL0. All other 13 PDE events were matched by corresponding SEL0 events. Note that some of the events are close together and that the symbols are superimposed on the map.

False Alarms for Test Periods between June 7 and 21, 2005, and between June 14 and 30, 2006

The rate of false alarms observed for SEL0 magnitudes mb 5 and above (IDC mb magnitude) was 40% for the time period in June 2005 (see Figure 3). This was significantly less than the false alarm rate observed for standard IDC operations (including all magnitudes) but not sufficient to reliably issue an alert based purely on this magnitude estimation. Most of the false alarms (14 out of 16) have only 1 or 2 defining station mb magnitudes (9 have 1 defining station mb, and 5 have 2 defining station mb).

In the meantime, we have implemented a quality control module in network processing to eliminate false alarms based on the difference between an estimated local station magnitude Ml and an estimated mb. If an event is defined by fewer than three stations and the difference between an estimated mb and Ml is larger than one magnitude unit, the event is considered to be a false event due to incompatibility in amplitudes between the stations. In addition to this module, we are screening detections based on SNR in the frequency band 0.8 to 4.5 Hz and identifying more of the low signal-to-noise ratio (SNR) detections as noise (Jia, 2006).

The false alarm rate at the level of SEL0 magnitude mb 5 and above has decreased significantly between June 2005 and June 2006, with just 2 false alarms out of a total of 21 events above magnitude 5 (see Figure 4). This is slightly under 10%. We attribute this improvement in part to the introduction of the quality control module eliminating small events with large discrepancies between Ml and mb and in part to an improvement in identifying low SNR detections as noise.

It is still desirable to improve on this magnitude estimation, for instance, by rapidly estimating an M_w magnitude for SEL0 events, given that we know that the IDC mb magnitude scale saturates rapidly for events with $M_w > 6$. Furthermore, a comparison between IDC and International Seismological Centre (ISC) magnitudes has shown that the IDC estimate of mb is on average smaller than the ISC estimate. We believe that the SEL0 bulletin at this stage could be a useful input to a decision-making process prior to issuing an alert. Its main advantage is its timeliness and the fact that we have not observed at this stage any missed event (for confirmed events with $M_w > 6$). It would be very advisable to include a quick expert review of the SEL0 results before an alert is released to discard potential false alarms.

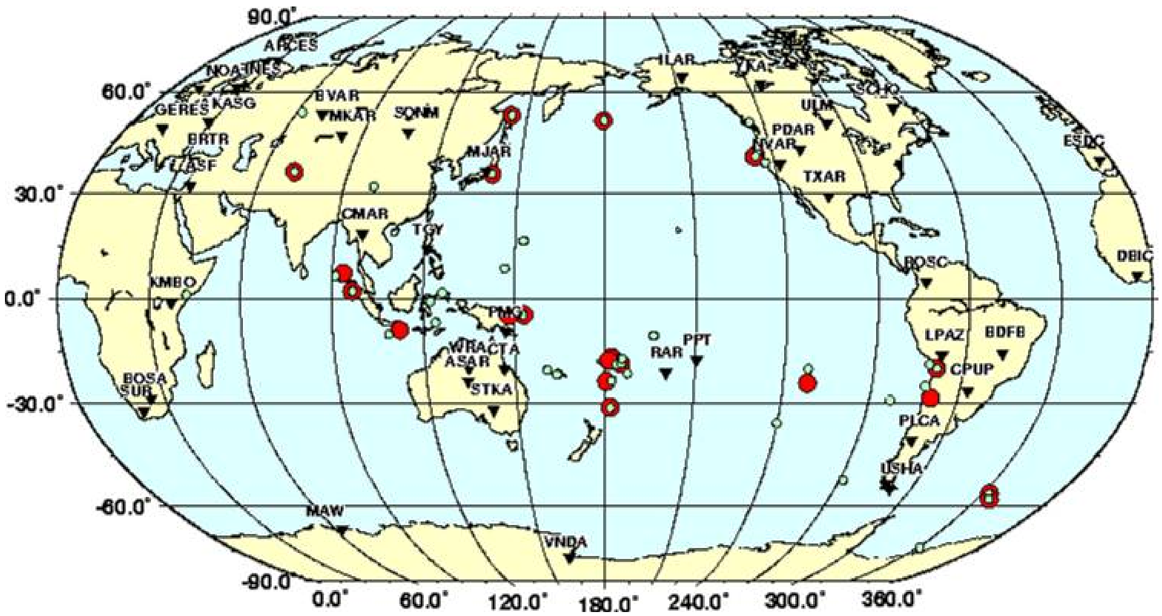

Figure 3. This map shows all 40 SEL0 events (in green) with mb > 5.0 during the time period June 7 to 21, 2005, and the matching PDE events (in red). Note the false alarm rate of about 40%. The SEL0 bulletin was using data from 41 stations, including some IMS auxiliary stations whose data was requested continuously.

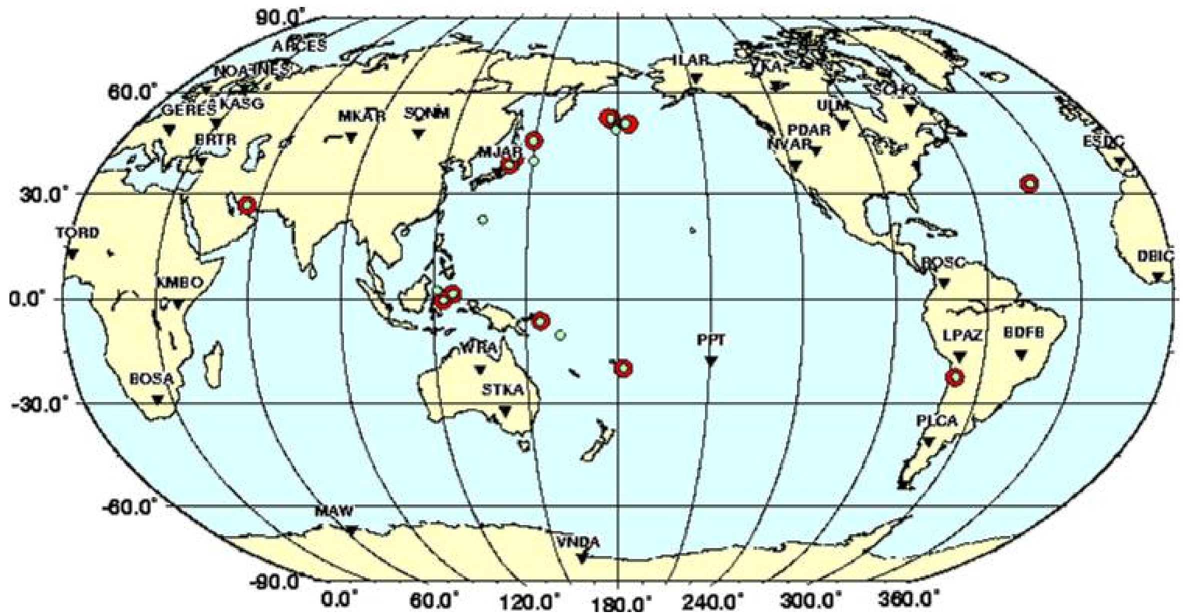

Figure 4. This map shows all 21 SEL0 events (in green) with mb > 5.0 during the time period June 14 to 30, 2006, and the matching PDE events (in red). Note that there are few false alarms during that time period. The SEL0 was using 30 stations during that time period.

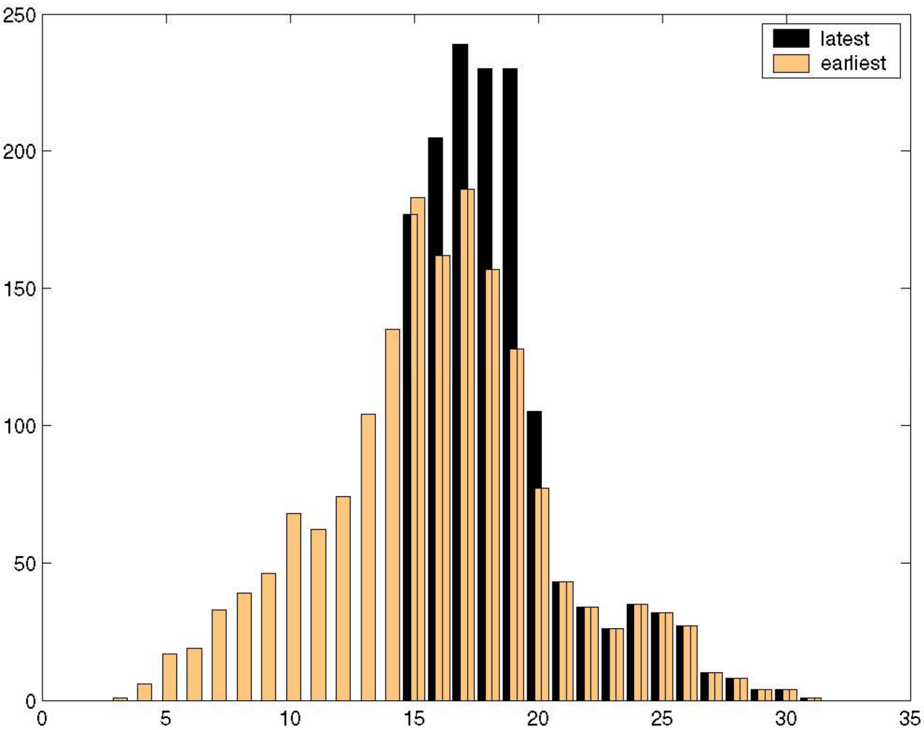

Figure 5. This histogram shows the distribution of events during the time period June 14 to 30, 2006. according to the time delay at which they were written in the SEL0 origin database table. Note that the majority of events are in the database 20 minutes after they occur.

Figure 5 shows the statistics of the time delays between the origin time and the time at which the events are written to the SEL0 origin database table, as well the equivalent statistics for an intermediate table (SEL0-EWS) that contains all events ever built by the system, as soon as they are built. The average delay is 16.4 minutes for the SEL0-EWS events and 18.9 minutes for the SEL0 events.

CONCLUSION(S) AND RECOMMENDATIONS

We have shown that it is possible to make adjustments to the CTBTO IDC software in order to produce a bulletin that can be useful as input to tsunami or other natural disaster warning centers. During relatively stable processing windows in June 2005 and June 2006 in a developmental context, we have shown that the timeliness objective can be obtained with a global bulletin produced within 20 minutes of real time. The SEL0 bulletin did not miss any event with M_w of 6 or more reported by the PDE bulletin during these two time windows with the exception of two events occurring during hardware failure and acquisition delay, respectively. We have seen an improvement in terms of false alarm rate for mb > 5 between June 2005 and June 2006. We are working on further reducing this false alarm rate and adding automatic fast computation of an M_w magnitude based on long-period P waves, which will give a better estimate of size for large events.

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DISCLAIMER

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission.

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