Answers to Tutorial No 5, Semester 2, 2023/2024

1. The first 8 notes of a well-known Singapore National Day song are: F4, E4, D4, D4, C4, C4, D4 and E4. What are the MIDI key numbers for these 8 notes? If the song is to be played by a player piano using a standard player piano paper roll, what are the paper roll track numbers for the first 8 notes of this song? Show how, in general, the MIDI key numbers can be converted to paper roll track numbers. If we start on C5 instead of F4, give the MIDI key numbers and the paper roll track numbers for these 8 notes, assuming that the notes of the song will still have the same interval relationships with the first note.

   Answer: Since the MIDI key number for F4 is 65, the MIDI key numbers for the 8 notes are: 65, 64, 62, 62, 60, 60, 62 and 64. The paper roll track numbers for the 8 notes are: 50, 49, 47, 47, 45, 45, 47 and 49. In general, the MIDI key numbers may be converted to paper roll track numbers by subtracting 15 from the corresponding MIDI key numbers. If we start on C5 instead of F4, the MIDI key numbers are: 72, 71, 69, 69, 67, 67, 69 and 71, and the paper roll track numbers are 57, 56, 54, 54, 52, 52, 54 and 56.

2. A MIDI interface box is connected to a desktop computer to enable the computer to send and receive MIDI messages through MIDI in and MIDI out sockets on the interface box. These sockets are labelled

IB and OB respectively. An electronic piano which has only MIDI in and MIDI out sockets labelled IP and OP respectively is used to send MIDI messages to the computer to compose a song on the computer. An electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively, an electronic organ has MIDI in, MIDI out and MIDI thru sockets labelled IR, OR and TR respectively, and an electronic synthesizer has MIDI in, MIDI out and MIDI thru sockets labelled IS, OS and TS respectively. The completed song is to be performed on the four electronic musical instruments (including the electronic piano). What are the connections which need to be made between the computer and the four electronic musical instruments (including the electronic piano), to enable the song to be composed and then performed as desired? If the electronic piano does have a MIDI thru socket, show how this affects the required connections.

Answer: In order for MIDI messages to be sent from the electronic piano to the desktop computer, the MIDI out OP of the electronic piano should be connected to the MIDI in IB of the MIDI interface box. In order to perform the completed song on all the four electronic musical instruments, the same MIDI messages have to be sent out through OB to the four instruments in sequence. For example, OB may be connected directly to either IG of the electronic tone generator, IR of the electronic organ or IS of the electronic synthesizer. For example, if OB is connected to IG of the electronic tone generator, the same MIDI messages should be sent out through TG to either IR of the electronic organ or IS of the electronic synthesizer. The same MIDI messages should then be sent out from the electronic organ or electronic synthesizer through their MIDI thru sockets to the MIDI input of the third electronic instrument. The electronic piano has to be the fourth and last instrument in the chain as it does not have a MIDI thru socket to pass on MIDI messages. If the electronic piano were to have a MIDI thru socket, it would then be able to pass on MIDI messages, and hence the four electronic musical instruments may be connected to the MIDI output of the MIDI interface box in any order.

3. The Singapore National Day song in question 1 is to be performed by an electronic synthesizer, starting on the note F4, by sending MIDI messages from a computer through a MIDI interface box to the MIDI input of the electronic synthesizer. The song is to be played by the clarinet MIDI instrument in the General MIDI or GM set of the electronic synthesizer, and the MIDI messages are to turn each note on and off in the lowest numbered MIDI channel as quickly as possible. What is the correct sequence of the MIDI messages to be sent to the electronic synthesizer, to enable the first 8 notes of the song to be played in the correct order?

   Answer: At the very beginning, a MIDI program change message should be sent to ensure that the electronic synthesizer plays the correct clarinet GM instrument. The first number in this message is 12 for a MIDI program change; the second number is 0 (indicating the lowest numbered MIDI channel), and the third number is 71 for the clarinet in the GM set (though the clarinet is actually instrument no. 72 in the GM set, the GM instruments are actually numbered starting from 0). For each note of the song, two MIDI messages should be sent: the first message should start with a 9 to turn the note on, and the second should start with an 8 to turn the note off. The second number in each message should be 0 for the lowest MIDI channel; the third number should be the key number for the note; and the last number should be 127 to indicate the fastest possible turn on and turn off velocities. The MIDI message decimal number sequence for the 8 notes of the song is as follows:

9, 0, 65, 127;
8, 0, 65, 127;
9, 0, 64, 127;
8, 0, 64, 127;
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 62, 127;
8, 0, 62, 127;
9, 0, 60, 127;
8, 0, 60, 127;
9, 0, 60, 127;
8 8, 0, 60, 127;
9, 0, 62, 127;
8, 0, 62, 127;

9, 0, 64, 127; and
8, 0, 64, 127.

4. 12 electronic organs are controlled through MIDI cables by a notebook computer, to enable all the organs to play a piece of music together. A particular chord is to be played simultaneously during the piece by all the 12 electronic organs. All the 12 organs should play the same number of notes of this chord. If we assume that all the notes of the chord have to be played within 0.09 seconds, what is the maximum number of notes which this chord can have? If the time duration is 0.11 seconds instead of 0.09 seconds, what is the maximum number of notes possible in the chord? (Assume that it takes exactly one millisecond for a MIDI message to go through the MIDI sockets of all the 12 electronic organs.)
   Answer: Since the MIDI messages are to be sent one after another and not simultaneously, and assuming that a single MIDI message takes exactly one millisecond to reach all the 12 electronic organs, within 0.09 seconds or 90 milliseconds, only 90 MIDI messages may be sent from the notebook computer to all the 12 electronic organs. Since one MIDI message is required to turn on each note in the chord, the total number of notes which each electronic organ can play is equal to 90 notes divided by 12 i.e. 7.5 notes. Since the number of notes played by each organ has to be an integer, each electronic organ can only play 7 notes, which means that the chord can

have no more than 7 notes times 12 organs i.e. 84 notes. If the time duration is 0.11 seconds or 110 milliseconds, the number of notes each electronic organ will be able to play is given by 110 notes divided by 12 i.e. approximately 9.167 notes. Hence each electronic organ will be able to play only 9 notes and the total number of notes in the chord is given by 9 notes times 12 i.e. 108 notes.

5. According to the Nyquist theorem, the sampling rate of a digital recording or transmission is double the highest frequency to be preserved in the recording or transmission. If, for example, the highest frequency to be preserved is f Hz, the sampling rate should be $2f$ samples per second. The highest frequency to be preserved is 18,500 Hz in a digital recording of a pop concert. If the bit length of the digital samples in the digital recording is 14 bits, calculate the bit rate of the recording. If we change the highest frequency to be preserved to 16,400 Hz, calculate the maximum possible bit length of the digital samples for the same bit rate. (Assume that the digital recording is in stereo, with two audio channels of equal bit rates to be digitally recorded.)
   Answer: By the Nyquist theorem, since the highest frequency to be preserved in the digital recording of the pop concert is 18,500 Hz, the sampling frequency is double this frequency i.e. 37,000 samples per second. Each of the two stereo audio channels thus has a bit rate of 37,000 samples per second times 14 bits i.e. 518,000 bits per second. Therefore for

the two audio channels the bit rate is twice this i.e. 1,036,000 bits per second. If the highest frequency to be preserved is 16,400 Hz instead of 18,500 Hz, the Nyquist sampling rate is now double 16,400 Hz i.e. 32,800 samples per second. If the bit rate is still 1,036,000 bits per second for two audio channels, for each channel the bit length of the digital samples will be given by 518,000 bits per second divided by 32,800 samples per second, which is approximately 15.79 bits. However, bit length should be an integer, so the bit length must be 15 bits. If the bit length were 16 bits, the bit rate would be 524,800 bits per second, which would be greater than the allowable maximum bit rate per channel of 518,000 bits per second.

Scientific Inquiry discussion points

(a) The invention of sound recording by Edison and others, and of radio transmission later, made it possible for music to be recorded and heard by many more listeners than hitherto. This was multiplied greatly and the fidelity of the recordings vastly improved when digital transmission and recording, coupled with smartphones and the Internet, made both live and recorded music easily accessible to a large proportion of the world's population. Hence the societal impact of science and technology can indeed be immense. Can you cite other scientific and technological innovations which had a similar or greater impact on society?

The invention of the telegraph around 1840 was *one of the most significant technological innovations in the history of human society. Prior to the telegraph, communicating a message had to be done through physical means, such as through messengers on horseback, or by using visible signals such as bright lamps or smoke signals. This meant that messages over hundreds or thousands of miles needed many hours or even days for transmission. The telegraph, which communicated messages over electrical wires, dramatically shortened the time needed to a matter of minutes. Only an "off-on" signal could be transmitted, so a code - the Morse code - was devised by Samuel Morse, one of the telegraph's principal inventors, to transmit numbers and the letters of the alphabet. Another innovation which had a similarly huge impact on society was the invention of the steam engine by Newcomen, Watt and others. The steam engine freed society from the constraints of human muscle power and the wind or water currents. Steamships made sea travel faster, safer and more reliable. Railway travel powered by steam locomotives dramatically shrunk travel times first in England and then in the rest of the World. Steam power also enabled and drove the Industrial Revolution which profoundly transformed human society.*