Answers to Tutorial No 5, Semester 1, 2024/2025

1. The first 10 notes of the chorus of a well-known Singapore National Day song are: C4, D4, E4, D4, C4, D4, E4, F4, E4 and D4. What are the MIDI key numbers for these 10 notes? Give the paper roll track numbers for the first 10 notes of this song which is to be played by a player piano using a standard player piano paper roll. How, in general, can the MIDI key numbers be converted to paper roll track numbers? Starting on G4 instead of C4, give the MIDI key numbers and the paper roll track numbers for these 10 notes, assuming that the notes of the song will still have the same interval relationships with the first note.

   Answer: The MIDI key number for C4 is 60, so the MIDI key numbers for the 10 notes are: 60, 62, 64, 62, 60, 62, 64, 65, 64 and 62. The paper roll track numbers for the 10 notes are: 45, 47, 49, 47, 45, 47, 49, 50, 49 and 47. In general, the MIDI key numbers may be converted to paper roll track numbers by subtracting 15 from the corresponding MIDI key numbers. Starting on G4 instead of C4, the MIDI key numbers are: 65, 67, 69, 67, 65, 67, 69, 70, 69 and 67, and the paper roll track numbers are 50, 52, 54, 52, 50, 52, 54, 55, 54 and 52.

2. A notebook computer is connected to a MIDI interface box which enables the computer to send and

receive MIDI messages through MIDI in and MIDI out sockets on the interface box which are labelled IX and OX respectively. An electronic organ which has only MIDI in and MIDI out sockets labelled IR and OR respectively is used to send MIDI messages to the computer to compose a song on the computer. An electronic synthesizer has MIDI in, MIDI out and MIDI thru sockets labelled IS, OS and TS respectively, an electronic tone generator has MIDI in, MIDI out and MIDI thru sockets labelled IG, OG and TG respectively, and an electronic piano has MIDI in, MIDI out and MIDI thru sockets labelled IP, OP and TP respectively. When the song has been completed, it is to be performed on the four electronic musical instruments (including the electronic organ). Give the connections which need to be made between the computer and the four electronic musical instruments (including the electronic organ), so that the song can be composed and then performed as desired. If the electronic organ does have a MIDI thru socket, how will this affect the required connections?

Answer: The MIDI out OR of the electronic organ should be connected to the MIDI in IX of the MIDI interface box to send MIDI messages from the electronic organ to the notebook computer. To perform the completed song on all the four electronic musical instruments, the same MIDI messages should be sent out through OX to the four instruments in sequence. For example, OX may be connected directly to either IS of the electronic synthesizer, IG of the electronic tone generator or IP of the electronic piano. If, for example, OX is connected to IS of the electronic synthesizer, the same MIDI messages should be sent out through TS to either IG of the electronic tone generator or IP of the electronic piano. The same MIDI messages should then be sent out from the electronic tone generator or electronic piano through their MIDI thru sockets to the MIDI input of the third electronic instrument. Since it does not have a MIDI thru socket to pass on MIDI messages, the electronic organ has to be the fourth and last instrument in the chain. If the electronic organ were to have a MIDI thru socket, it would then be able to pass on MIDI messages, so that the four electronic musical instruments may be connected to the MIDI output of the MIDI interface box in any order.

3. An electronic organ is to perform the Singapore National Day song in question 1, starting on the note C4, by sending MIDI messages from a computer through a MIDI interface box to the MIDI input of the electronic organ. The clarinet MIDI instrument in the General MIDI or GM set of the electronic organ is to play the song, and the MIDI messages are to turn each note on and off in the highest numbered MIDI channel as quickly as possible. Give the correct sequence of the MIDI messages to be sent to the electronic organ, to enable the first 10 notes of the song to be played in the correct order.
   Answer: A MIDI program change message should

be sent at the very beginning to ensure that the electronic organ plays the correct clarinet GM instrument. The first number in this message is 12 for a MIDI program change; the second number is 15 (indicating the highest 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 15 for the highest 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. Therefore the MIDI message decimal number sequence for the 10 notes of the song is as follows:

9, 15, 60, 127;
8, 15, 60, 127;
9, 15, 62, 127;
8, 15, 62, 127;
9, 15, 64, 127;
8, 15, 64, 127;
9, 15, 62, 127;
8, 15, 62, 127;
9, 15, 60, 127;
8, 15, 60, 127;
9, 15, 62, 127;
8, 15, 62, 127;

9, 15, 64, 127;
8, 15, 64, 127;
9, 15, 65, 127;
8, 15, 65, 127;
9, 15, 64, 127;
8, 15, 64, 127;
9, 15, 62, 127; and
8, 15, 62, 127.

4. A desktop computer controls 14 electronic organs through MIDI cables to enable all the organs to play a piece of music together, and one particular chord is to be played simultaneously during the piece by all the 14 electronic organs. If all the 14 organs play the same number of notes of this chord, and if we assume that all the notes of the chord have to be played within 0.12 seconds, calculate the maximum number of notes which this chord can have. If the time duration is 0.1 seconds instead of 0.12 seconds, what is the maximum number of notes that the chord can have? (Assume that it takes exactly one millisecond for a MIDI message to go through the MIDI sockets of all the 14 electronic organs.)
   Answer: The MIDI messages are to be sent one after another and not simultaneously, so if we assume that a single MIDI message takes exactly one millisecond to reach all the 14 electronic organs, within 0.12 seconds or 120 milliseconds only 120 MIDI messages may be sent from the desktop computer to all the 14 electronic organs. One MIDI message is re-

quired to turn on each note in the chord, so the total number of notes which each electronic organ can play is equal to 120 notes divided by 14 i.e. approximately 8.57 notes. However, the number of notes played by each organ has to be an integer, so each electronic organ can only play 8 notes. Hence the chord can have no more than 8 notes times 14 organs i.e. 112 notes. If the time duration is 0.1 seconds or 100 milliseconds instead of 120 milliseconds, the number of notes each electronic organ will be able to play is equal to 100 notes divided by 14 i.e. approximately 7.14 notes. Each electronic organ will thus be able to play only 7 notes and the total number of notes in the chord is equal to 7 notes times 14 i.e. 98 notes.

5. The Nyquist theorem says that the sampling rate of a digital recording or transmission is double the highest frequency to be preserved in the recording or transmission. For example, if the highest frequency to be preserved is f Hz, the sampling rate should be $2f$ samples per second. In a digital recording of a folk music concert, the highest frequency to be preserved is 16,800 Hz. If the bit length of the digital samples in the digital recording is 15 bits, what is the bit rate of the recording? If we change the highest frequency to be preserved to 19,400 Hz, what would be 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: Since the highest frequency to be pre-

served in the digital recording of the folk music concert is 16,800 Hz, by the Nyquist theorem the sampling frequency is double this frequency i.e. 33,600 samples per second. Therefore each of the two stereo audio channels has a bit rate of 33,600 samples per second times 15 bits i.e. 504,000 bits per second. For the two audio channels the bit rate is twice this i.e. 1,008,000 bits per second. If we change the highest frequency to be preserved to 19,400 Hz instead of 16,800 Hz, the Nyquist sampling rate would now be double 19,400 Hz i.e. 38,800 samples per second. If the bit rate is still 1,008,000 bits per second for two audio channels, for each channel the bit length of the digital samples will be given by 504,000 bits per second divided by 38,800 samples per second, i.e. approximately 12.99 bits. Since bit length has to be an integer, the bit length must be 12 bits. If the bit length were 13 bits, the bit rate would be 504,400 bits per second, which would be exceed the allowable maximum bit rate per channel of 504,000 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.*