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Simulink based RNN models to solve LPM

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Abstract
Recurrent artificial neural network has shown great success because of its interesting feature, each neuron in this type of artificial neural acts a computational element with memory, providing a neuron with ability to store the calculated output for the next stage of computation.
In this paper we will introduce a methodology base on RNN features, this methodology will be used to build and run simulink based RNN models to solve linear programming problems, the introduced simulink models will be implemented in order to find the optimal values of LPM.

Keywords: ANN, RNN, LPM, constraint, objective function, optimal solution, linear AF, poslin AF

1. Introduction

1.1 Linear programming model

Problems-based on linear programming are defined as the problems of maximizing the profit (or minimizing the cost), which is a linear function subject to linear constraints [1, 2].
Linear programming model (LPM) is usually constructed by:
- The profit (cost) equation, which requires maximization (minimization).
- A set of constraints, each of them is restricted to a constant.

$$Z = c_1\, x_1 + c_2\, x_2 + \ldots\ldots\ldots\ldots\ldots + c_n\, x_n$$

subject to the constraints

$$a_{11}\, x_1 + a_{12}\, x_2 + \ldots\ldots\ldots\ldots + a_{1n}\, x_n \le b_1$$

$$a_{21}\, x_1 + a_{22}\, x_2 + \ldots\ldots\ldots\ldots + a_{2n}\, x_n \le b_2$$

....

$$a_{m1x1} + a_{m2x2} + \ldots\ldots\ldots\ldots + a_{mnxn} \le b_m$$

So the LP problem is to find the values for the variables $x_1, x_2, \ldots\ldots\ldots\ldots, x_n$ which maximize (minimize) the objective function [3, 4].
All the variables must meet the restriction:

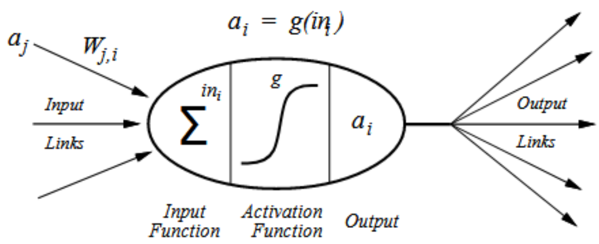
$$x_1,\ x_2,\ \ldots\ldots\ldots\ldots,\ x_n \ge 0$$

Here we have to notice the following:
1. A set of values $x_1, x_2, \ldots\ldots\ldots\ldots, x_n$ which satisfies the constraints is called its solution.
2. Any solution to a problem which satisfies the non-negativity restrictions of the problem is called its feasible solution.
3. Any feasible solution which maximizes (or minimizes) the objective function is called its optimal solution.

For any linear LP problem, we have to follow the following rules in order to build an LPM:
Step 1: Mark the unknowns in the given by x and y.
Step 2: Formulate the objective function.
Step 3: Translate all the constraints in the form of equalities.
Step 4: Solve these equalities simultaneously.
Step 5: Find the values of *x* and *y* for which the objective function $z = ax + by$ has maximum or minimum value (as the case may be).

1.2 Recurrent artificial neural network (RNN)

Artificial neural network (ANN) is a powerful computational model, it contains a set of neurons, these neurons are organized into layers, and the neurons in ANN are fully connected via weights [5, 6, 7].
Each neuron performs the summation of products as shown in figure 1, then according to the selected activation function for the layer computes the output of this neuron [8, 9, 10].



$$a_i = g\left(\sum_j W_{j,i} a_j\right)$$

Fig 1: Neuron operations

Here in these ANN structures the output of each neuron always depends on the inputs, the selected weights, and the selected activation function [11, 12].
In a traditional ANN we always assume that all inputs (and

outputs) are independent of each other [11, 12]. But for many applications such as prediction task and natural language processing task it will be a bad idea to used traditional ANN. RNNs are called *recurrent* because they perform the same task for every element of a sequence [13, 16] with the output being depended on the previous computations and the previous states. On another hand we can assume that RNN is a computational model (like ANN) but it has a "memory" which captures information about what has been calculated so far [14, 15].

A single neuron RNN computes the output and returns this output to the input as shown in figure 2:

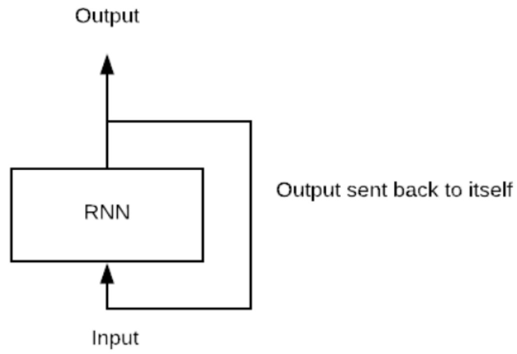


Fig 2: Single neuron RNN

A single neuron RNN can be adapted to simulink model as shown in figure 3:

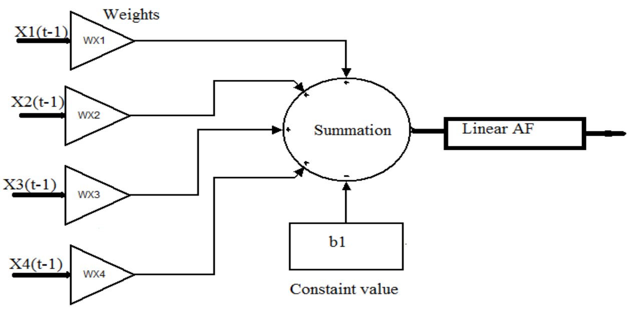


Fig 3: A single neuron representation in simulink

For the constraint: $5x1 + 4x2 + x3 + 0x4 \leqslant 60$ the neuron will be as shown in figure 4:

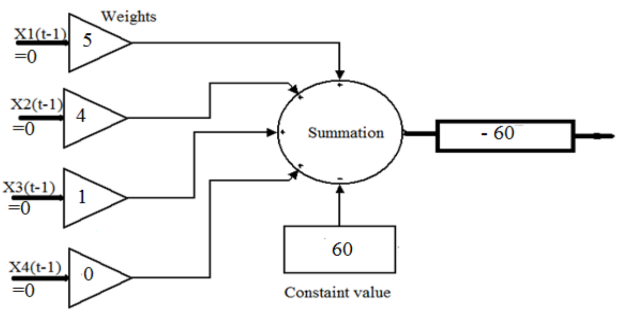


Fig 4: RNN neuron for a selected constraint

2. Proposed methodology to represent LPP using simulink model based on RNN

LPM is constructed by an objective function and a set of equations, one for each constraint, the objective function usually depends on some variables and here we must add some slack variables to solve the un equality in each constraint, one slack variable for each constraint.

The RNN architecture for any LPM will be as shown in figure 5:

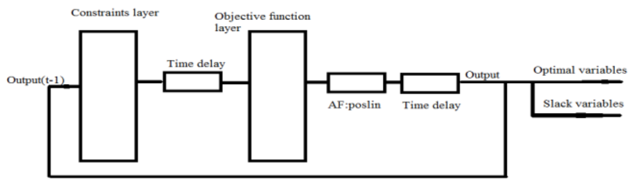


Fig 5: RNN for LPP

To represent LPP using simulink based on RNN we have to follow the following steps:

i) Creating constraints layer

For each constraint we have to create simulink neuron as shown in figure 3, the output of this neuron must be connected to a gain (model parameter (mp1)) with value less than 1, this parameter will control the model output to reach the optimal value, the calculated output must be passed to a delay time to save this value for next calculation. The calculated outputs for time (t) and time (t-1) must be summed to be used as an input to the second layer (objective function layer).

ii) Creating objective function layer

The objective function layer must contain number of neurons equal to the number of variables used in LPM, one neuron for each variable (including slack variables). The weights for each neuron are the parameters of each variable in each constraint and the constant is the parameter of the variable in the objective function.

The output of each neuron in this layer must be passed to poslin AF in order to omit the negative results and make them equal zeros. The poslined outputs must be passed to a gain(model parameter mp2) to control the outputs, then the calculated value must be passed to a time delay in order to save the previous outputs for summation, the outputs of this layer must give the optimal values for LPM variable and they must feed the constraint layer to enhance the values of the variables(when they are not optimal).

To make this methodology clear let us take the following LPM:

$$max y = 5x1$$

Subject to:

$$2x1 \leq 25$$

The optimal solution of this model is x1=12.5

This model contains 1 constraint:

$$2x1 + x2 - 25 = 0$$

Applying the methodology, we can reach the following simulink model (see figure 6):

Here we have 2 layers: the constraints layer contains 1 neuron and the objective function layer contains 2 neurons:

Let us select the model parameters (n1=0.1, m2=1, m2=1)

Running this model will give us the optimal solution for x1 after 31 time iterations as shown in figure 7, we have to notice that the value of x1 after using extra iterations time will remain the same (see figure 8)

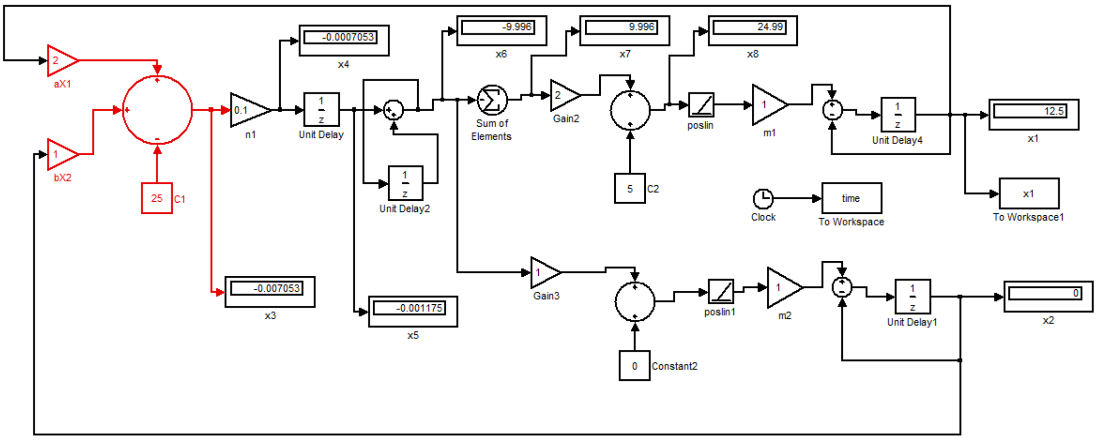


Fig 6: Model example 1

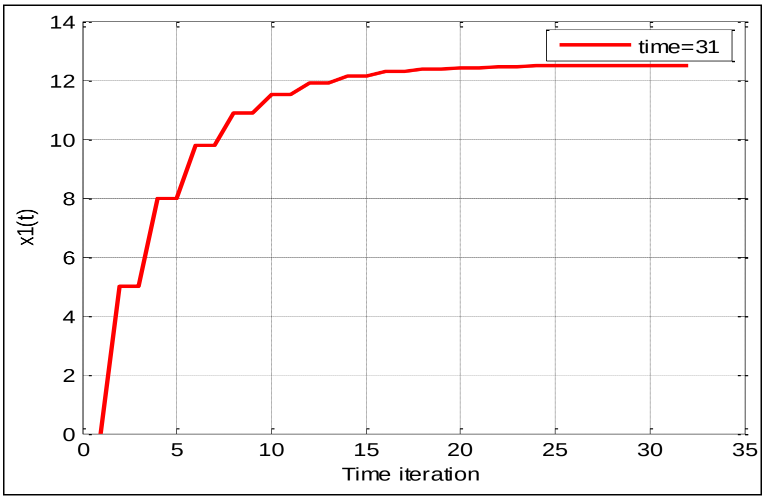


Fig 7: x1 after 31 time iterations

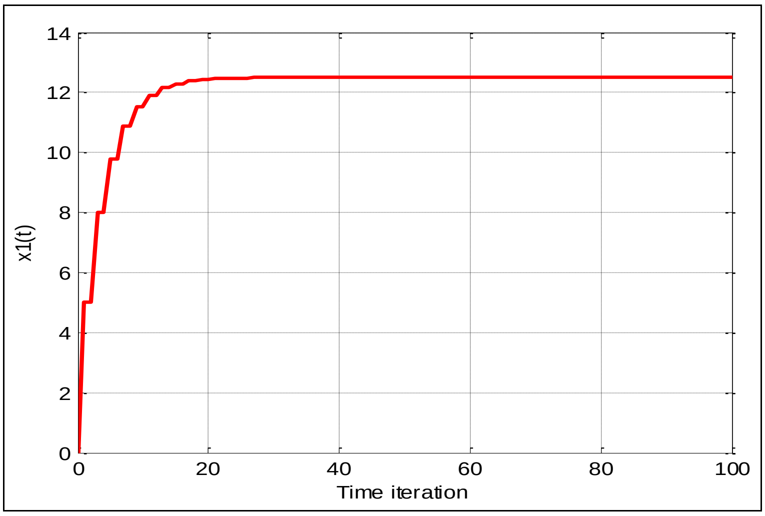


Fig 8: x1 after 100 time iterations

Here we have to professional in selecting model parameters (n and m) table 1 shows how the selected values of these parameters affect the value of x1 and number of time iteration:

Table 1: Model 1 implementation results

Model parameters			Number of time iterations	Calculated x1 value	Remarks
n1	m1	m2			
0.1	0.1	1	3900	12.49	Optimal not reached
0.1	0.1	1	3950	12.50	Optimal reached
0.1	0.1	1	3950	12.50	Optimal
0.5	0.5	1	2	12.50	Optimal reached
0.5	0.5	1	20	12.50	optimal
0.5	0.5	0.5	2	12.50	Optimal reached
0.01	0.01	0.5	35000	12.49	Optimal with error
0.01	0.01	0.5	36000	12.49	Optimal with error
0.6	0.1	1	55	12.49	Optimal with error
0.6	0.1	1	58	12.50	Optimal reached
0.6	0.1	1	100	12.50	optimal
1	1	1	2	15	No optimal
1	1	1	10	15	No optimal
0.1	0.01	1	3950	12.5	Optimal reached

3. Using the proposed methodology to implement real LPM

Now let us use the proposed methodology to build and run some RNN simulink models to solve linear programming problems:

Let us take the following LPM:

$$max y = 40x1 + 50x2$$

Subject to:

$$2x1 + x2 \leq 32$$

$$2x1 + 3x2 \leq 48$$

Here we have to write this model in a standard form by adding slack variables:

$$2x1 + x2 + x3 - 32 = 0$$

$$2x1 + 3x2 + 0x3 + x4 - 48 = 0$$

The RNN simulink model as shown in figure 9 will contain 2 layers:

- The constraint layer, which contains 2 neurons, 1 for each constraint.
- The objective function layer, which contains 4 neurons, one for each variable (including the slack variables).

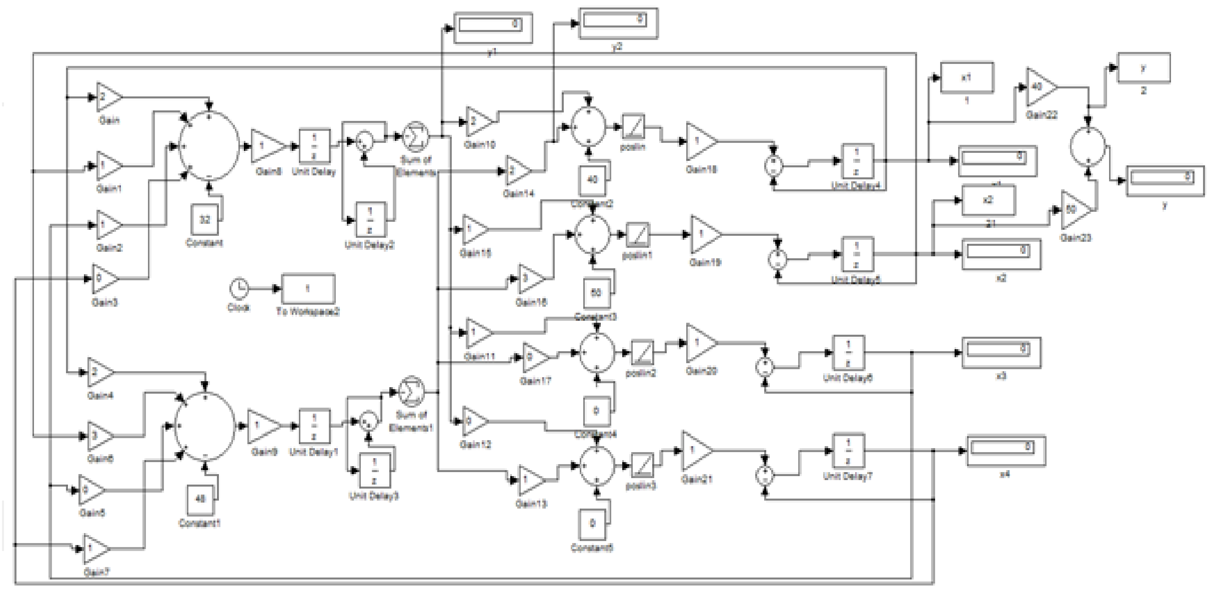


Fig 9: RNN simulink model for real LPM

This model was implemented for the model parameters: Gain8=0.015; Gain18=-0.07; Gain19=0.035; Gain20=0.02; Gain21=0.02 and with 6000 time iterations the output was very closed to optimal solution as shown in figure 10:

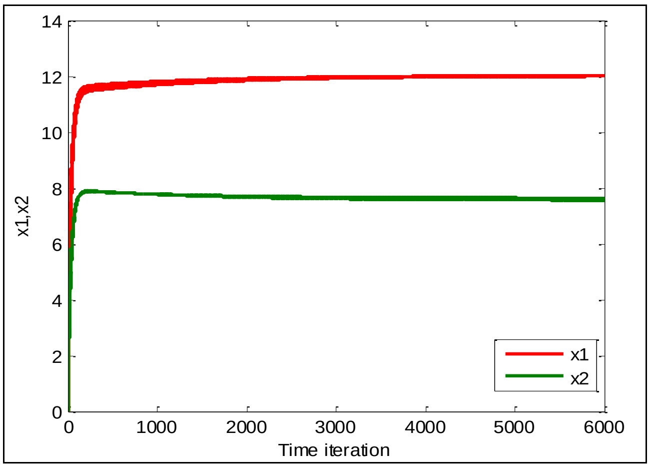


Fig 10: Simulation results of LPM1

Adjusting the model parameters for: Gain 8=0.015; Gain9=0.08; Gain18=-0.0825; Gain19=0.09325; Gain20=0.015; Gain21=0.05 and with 4000 time iterations the output was very closed to optimal solution as shown in figure 11:

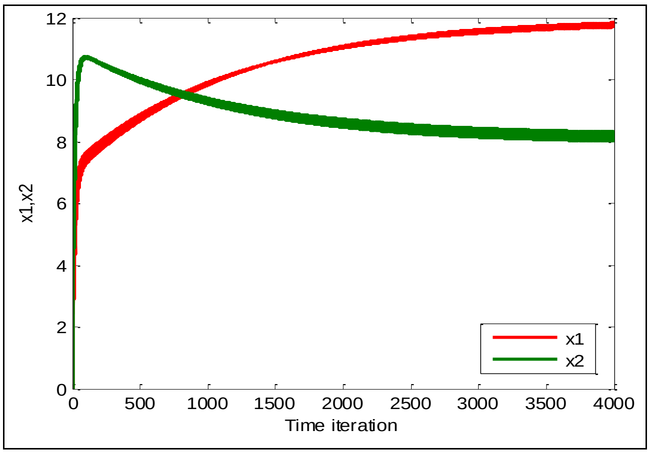


Fig 10: Simulation results of LPM1 after updating model parameters

The RNN simulink model shown in figure 9 suits any LPM with 2 constraints, the only thing needed is to adjust the weights in the constraint and objective function layers and to update the base constants connected to each neuron.

For LPM with 3 and constraint, the model shown in figure 9 must be updated as follows:

- Add an extra neuron in the constraint layer for each extra constraint.
- Add one neuron in the objective function layer for each extra variable (including the slack variables).

The above explained model was adjusted and implemented for various LPMs with 2 and 3 constraints; the obtained solutions were equal the optimal solution or very closed to them (with error less than 1.4%, but selecting the appropriate values for the model parameter will lead the error to zero).

4. Conclusion

The feature of RNN as a computing element with memory was used to build and run simulink models.

A methodology of creating simulink based RNN models to be used for LPM solving was introduced. Some LPM were selected, simulink models were built and tested, the experimental results showed that constructed simulink model using the proposed methodology was accurate and always gave the optimal solution of LPM.

The simulink models are very simple to construct, and the constructed model can be easily updated to suit any LPM with any number of constrains, and number of variables and any objective function.

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