BLOOD PRESSURE SENSOR BT17i

USER'S GUIDE

CENTRE FOR MICROCOMPUTER APPLICATIONS

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Short description

The Blood Pressure sensor BT17i allows measuring arterial blood pressure. The sensor measures the pressure in the connected cuff caused by the interaction between the cuff and the blood flow through the brachial artery. The systolic and diastolic blood pressure can be calculated using the oscillometric method (non-invasive method).
The Blood Pressure sensor consists of:

- a pressure sensor with measurement range between 0 .. 375 mmHg,
- a standard adjustable blood pressure cuff (size: 24 cm to 35 cm),
- a bulb pump with a control valve.

The blood pressure cuff consists of an inflatable bladder connected by one hose to a hand pump bulb and by a second hose to the pressure sensor box. The user can set the rate of cuff deflation manually with the control valve.
The sensor produces an output voltage, which varies linear with the measured pressure. The special circuitry in the sensor minimizes errors due to temperature changes.

The Blood Pressure sensor can be directly connected to the analog BT inputs of the CMA interfaces. The sensor cable BT - IEEE1394 needed to connect the sensor to an interface is not supplied with the sensor and has to be purchased separately (CMA Article BTsc_1).

Important:
The Blood Pressure sensor is not appropriate for medical applications. This sensor is to be used only for educational purposes. Read this manual before you start measurements with the sensor. Notice that over inflation of the cuff may cause pain and/or injury.

Sensor recognition

The Blood Pressure BT17i has a memory chip (EEPROM) with information about the sensor: its name, measured quantity, unit and calibration. Through a simple protocol this information is read by the CMA interfaces and the sensor is automatically recognized when it is connected to these interfaces. If your Blood Pressure sensor is not automatically detected by an interface, you have to manually set up your sensor by selecting it from the Coach Sensor Library.

Calibration

The Blood Pressure sensor is supplied calibrated. The output of the Blood Pressure sensor is linear with respect to pressure. The calibration function is:

$$p\ (\text{mm Hg}) = 83.34 * V_{out}(V) - 16.67$$

The Coach software allows selecting the calibration supplied by the sensor memory (EEPROM) or the calibration stored in the Coach Sensor Library. For better accuracy the pre-defined calibration can be shifted.

How the Blood Pressure Sensor works

1. About blood pressure

During each heart beat the arterial blood pressure varies between two utmost values: the systolic and the diastolic pressure. The peak pressure in the arteries is the systolic pressure and the lowest pressure is the diastolic pressure. In between these is the Mean Arterial Pressure (MAP), which is used to describe the average blood pressure.

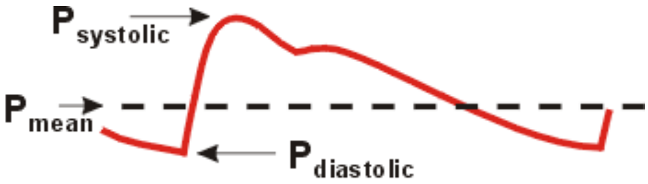

Figure 1. *Pressure course of the heart beat in the brachial artery.*

2. Oscillometric method

The blood pressure sensor allows determining blood pressure via the so-called oscillometric method. With this non-invasive method, a cuff is placed around the arm and inflated by means of a pump, after which the cuff deflates via a control valve. The sensor measures the pressure of the air in the cuff.
With inflation of the cuff, the external pressure on the artery rises. At pressures exceeding the systolic blood pressure, the artery will be occluded, no blood flow occurs through the artery. When the cuff is slowly deflated, the cuff pressure, and hence the external pressure on the artery will be lowered to that of the systolic blood pressure. Now, the artery is no longer continuously occluded. At systolic blood pressure, small amounts of blood flow through the compressed artery and cause changes in the artery volume, conducted to the cuff. This leads to detectable pressure oscillations in the cuff. These oscillations increase with lower cuff pressure values, as more blood passes through the compressed artery. The maximum oscillation amplitude is reached around the mean arterial blood pressure. Then, as the pressure decreases until the cuff becomes fully deflated, the blood flow returns to normal and the oscillation amplitude decreases and small pulses remain at a low level below diastolic pressure.
A similar method is used during the regular blood pressure measurement, a clinician, using the stethoscope, listens at the brachial artery for characteristics sounds of the pressure pulses (so-called Korotkoff sounds).

Measurements with the Blood Pressure sensor

Safety instructions

The cuff is put around the upper arm and produces pressure on the brachial artery. To reduce the risk on injuries and pain it is important to read and follow the following safety instructions:

- Put on the cuff as described in the next section of the manual.
- Do not inflate the cuff to a pressure above 180 mmHg. ***Over inflation of the cuff may cause pain and/or injury***.
- Deflate the cuff immediately using the control valve when the pressure in the cuff exceeds 200 mmHg.
- Measurements with the cuff around the upper arm should **not take longer than 3 minutes**. In any case deflate the cuff immediately using the control valve when the

cuff is inflated around the upper arm for more than 5 minutes.

- There should be at least 10 minutes break between two measurements on the same individual.

Placing the cuff around the upper arm

When performing blood pressure measurements, it is best to work with a partner.

1. Connect the Blood Pressure sensor to your interface.
2. Attach the rubber hose from the cuff to the connector on the sensor.
3. Uncover the upper arm of the test person and let the person sit with his arm at chest height.
4. Wrap the cuff firmly around the upper arm, approximately 2-3 cm above the elbow. The two rubber hoses from the cuff should be positioned over the bicep muscle (brachial artery) and hanging down. The labels on the cuff indicate the correct placement.

Adjusting the control valve

The release rate of the pressure in the cuff is adjusted with the control valve. The valve is controlled by a simple wheel. As the wheel is rotated the deflation rate is adjusted.
The actual blood pressure measurement should take between 60 and 120 seconds, so the pressure valve should be set to an approximate deflation rate between 2 and 3 mmHg/s. This slow rate of cuff deflation is necessary for accurate measurement.

5. Make a test measurement to adjust the control valve and find out the optimal deflection rate.
   - Start your measurement.
   - Inflate the cuff up to a pressure between 150 mmHg and 170 mmHg by squeezing the rubber air bulb several times.
   - During the deflation of the cuff adjust the deflection rate by turning the wheel. Turn the wheel clockwise to let the cuff deflate more quickly and shorten the measurement time. Turn the wheel counter clockwise to let the cuff deflate slower and extend the measurement time.
   - When the pressure wheel is set you are ready to collect data.

Collecting data

After the cuff is placed correctly on the arm and the control release valve is adjusted you can start your measurement.

6. Lay down the arm of the test person on the table with an open hand.
   Important: *The test person must remain still during data collection—no movement of the arm or hand during measurements.*
7. Start your measurement.

8. Quickly and repeatedly squeeze the bulb to inflate the cuff on the test person's arm. Continue inflating the cuff to a pressure between 150 and 170 mm Hg. When this pressure is reached, set the bulb pump down onto the table. The built-in pressure release valve will slowly deflate the cuff.
9. After the measurement is finished, release the remaining air in the cuff by turning the valve. You should be able to hear air coming out of the cuff.

Extra tips

Blood pressure readings will differ from person to person and even between measurements on the same individual. Do not expect to receive the same measurements each trial since there are many factors that cause a person's blood pressure to increase or decrease. Use the following tips to take accurate measurements:

- The test person's arm and hand must remain still during measurements; hand open – no fist!
- The arm should be at heart level and is best supported.
- Proper placement of the pressure cuff will increase the accuracy of your blood pressure measurements.
- Remove any clothing that may cover or constrict the portion of the arm being measured.
- The blood pressure increases with the age. The rule of thumb for the normal systolic pressure is the formula 100 + age.
- Blood pressure values are rounded to 5 mmHg.

Determining the heart rate

The heart rate (beats per minute) can be calculated using the following formula:

$$heart\ rate = \frac{[number\ of\ maxima] - 1}{[time\ of\ the\ last\ maximum] - [time\ of\ the\ last\ maximum\ ]} * 60$$

- Count the number of local maxima in the descending part of the graph.
- In addition, use the scan option to read out the time of the first and the last maxima.
- Calculate the heart rate.

Determining the blood pressure

The result of the measurement with the Blood Pressure sensor is a pressure versus time graph, in which the pressure pulses of the blood are superposed on the decaying trend pressure of the cuff.

1. Determining the blood pressure manually from the graph

The simple method of determining the blood pressure is manually, directly from the pressure graph. The point at which the largest pressure pulses are occurring corresponds to the Mean Arterial Pressure (MAP). The point above the mean pressure at which the pressure difference grows rapidly correlates to the systolic pressure. The point below the mean pressure where the differences start to get small corresponds to the diastolic pressure.

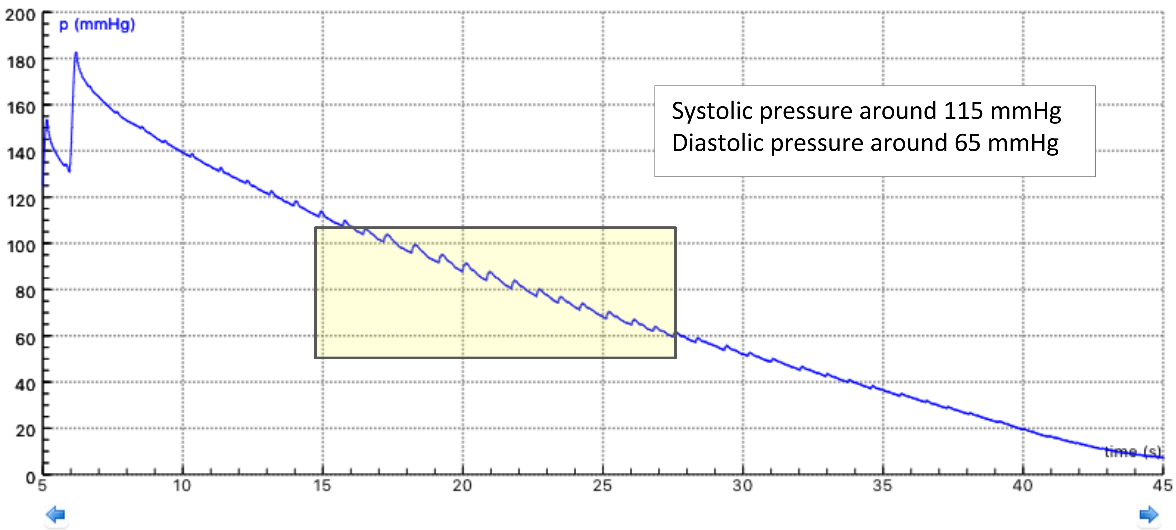

***Figure 2**. A typical measurement with the Blood Pressure sensor.*

1. Identify the largest pressure "pulse". This is an estimation of the MAP.
2. Identify when the data begins forming rapid "pulses". This is an estimation of the systolic pressure.
3. Identify when the data stops forming smaller "pulses". This is an estimation of the diastolic pressure.

2. Determining the blood pressure using oscillometric method

A more precise but laborious method to determine the blood pressure is the oscillometric method. The pressure pulses, when extracted from the cuff pressure, form an oscillating waveform. The peak-to-peak amplitudes of this waveform vs. pressure create a bell shaped "envelope curve" (see figure 5). Within the envelope, the pressure pulse amplitudes increase until maximum amplitude is reached (this point corresponds to the MAP). After that the pulse amplitudes decrease further until hardly noticeable. Generally, the systolic blood pressure is found by determining the point along this bell-shaped envelope for pressure above MAP and for which the value of the pressure amplitude is 50% of the maximum amplitude value. The diastolic blood pressure is found using the same method for pressure below MAP and having an amplitude value of 75% of the maximum amplitude value. These percentage values are obtained from empirical research.[1]

When this method is applied to the measured pressure graph, the bell shaped "envelope curve" is extracted from the measurement graph as the difference graph of the pulse pressure graph (the maximal values of the pressure pulses) and the cuff deflection trend pressure graph. This procedure is described below in details for the Coach program starting from version 7.3[2], in 4 steps:

I. Determining the cuff (trend) pressure
II. Determining the pulse pressure
III. Determining the envelope curve
IV. Determining the blood pressure

I. Determining the cuff (trend) pressure

[1] Mehlsen J et al (1999). Vejledende retnigslinier for hjemmeblodtryksmåling. Ugesk Læ Klaringsrapport nr. 8, 1999.
[2] If you use an older version of the Coach program consult the CMA Blood Pressure Sensor 0377i User's Guide.

1. From the data table determine the number of the measured points. In this description we assume that the measured data are stored in Run 1.
2. Right-click the graph and select *Analyze/Process > Select/Remove Data*.
3. Select under Run the option *Run 1* and select under Selection method *Point-by-point*.
4. Mark the very first point, very last point and points where the pressure values are locally minimal. These points indicate the deflating pressure trend of the cuff (i.e. without the pulses). You may take every second minimum.
   Tip: In Coach you can maximize the Select/Remove Data dialog. Find the point where the pressure value (displayed in the pressure coordinate field) is locally minimal.

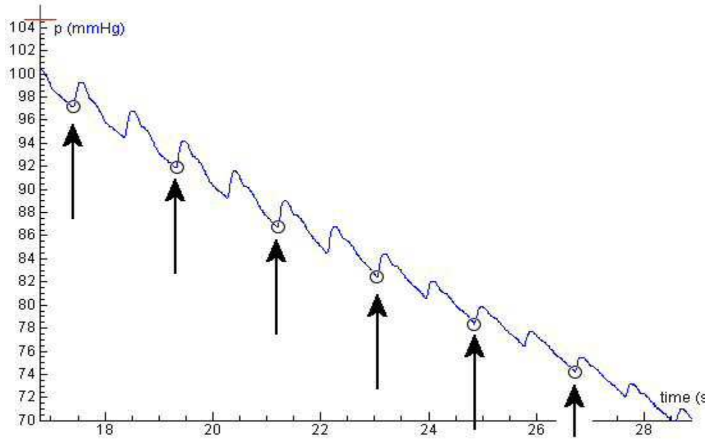

***Figure 3**. Select the points at which the pressure value is minimal, just before the pressure signal rises again.*

5. Mark *Keep selected* and click *OK*. As the result you get Run 2 with only the selected data points. These points determine the graph of the trend pressure.
6. To extend the number of points in the graph you can smooth the graph.
   - Right-click the graph and select *Analyze/Process > Smooth*.
   - Select under Run the option *Run 2* (with the selected lower points).
   - Select the method *Spline*.
   - Click *Plot* to draw the smooth graph.
   - Click *OK* to accept.
   - Type the number of points of the original pressure graph (determined in step 1) in the *Number of Points* field and confirm.
   - As a result you get a new Run 3 with many more points. These are the trend pressure data. You can rename this run into **p_trend**.

II. Determining the pulse pressure

7. Repeat the steps 2 to 5. Mark the very first point, very last point and this time mark the maximal pressure values, the tops of the pulses. Take the upper points just after the lower points, so you will get exactly the same number of selected data (see figure 3 and 4).
8. As the result you get Run 4 with the selected upper data points. These are the pressure pulses.
9. Repeat step 6 to smooth the data. As the result you get Run 5 with

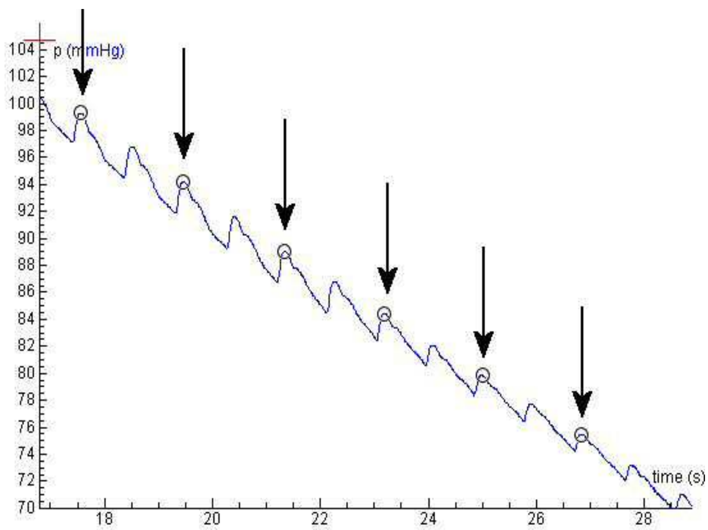

***Figure 4**. Select the points at which the pressure value is maximal, just when pressure signal rises.*

more points. These are the pulse pressure data, you can rename this run into **p_pulse**.

III. Determining the envelope curve

10. To be able to calculate the pressure difference first copy the pressure data from Run 3 **p_trend** into Run 5 **p_pulse**.
    - Select a data series (at the right side of the table) or select a cell in a column of the data series of Run 3.
    - When you start to drag a variable heading **p** the cursor changes into a graph icon. Continue dragging until you place the cursor over run number 5, at the left side of the table (to this run you are copying the data).
    - When the run number is selected (a blue frame appears) release the icon. A new variable column with the heading *Copied of p(mmHg)* will be added to Run 5.
    - The data points from the column *p (mmHg)* of Run 3 are now copied into a new column *Copy of p (mmHg)* of Run 5. You can see it by opening Run 5. You can rename the variables to reflect the above: *p* to *p_pulse* and *Copy of p* into *p_trend*.
11. Calculate a new variable **p_difference**.
    - Right-click the Data Table and select *Add a new variable > Into Data Series > Formula*.
    - Give this variable the name *p_difference* and unit *mmHg* and enter the formula: *p_pulse – p_trend*. This calculates the pressure difference.
12. Create a new graph **Envelope curve**, which displays *p-difference* against *p-trend*. The resulting graph has a bell-shape form.
13. Use the function fit option to approximate the graph with a function.
    - Right-click the *p-difference* vs. *p-trend* graph and select *Analyze/Process > Function fit.*
    - Select under Run the option *Run 5* (where the calculations were made).
    - Select the function $f(x)=a*exp(-(bx+c)^2)+d$.
    - Press *Estimate.* If necessary manually adjust the individual parameter values and press *Refine.* Press *OK* when you are satisfied with the result. The fit will be added as a new variable *Fit of p_difference5* in the graph.

IV. Determining the blood pressure

The blood pressure values can be determined directly from the envelope curve or via its derivative graph.

Method 1 - directly from the Envelope curve (see figure 5):

14. Use the Scan option to read the highest point in the envelope curve. This point corresponds to the Mean Arterial Pressure (MAP).
15. Determine the systolic and diastolic pressures.
    - The systolic blood pressure is found as the pressure value at the point along this bell-shaped envelope for pressure above MAP, for which the pressure difference value is 50% of the pressure difference corresponding to MAP.
    - The diastolic blood pressure is found as the pressure value at the point along this bell-shaped envelope for pressure below MAP, for which the pressure difference value is 75% of the pressure difference corresponding to MAP.

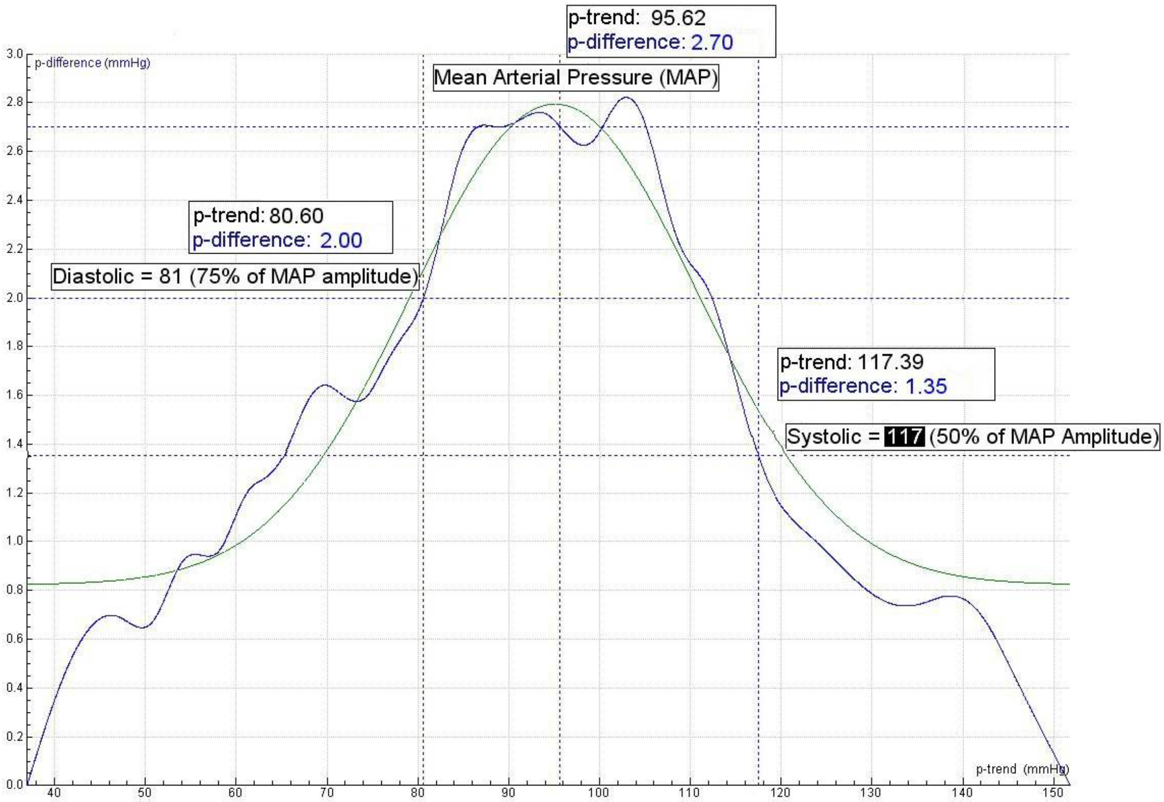

Figure 5: *A bell shaped "envelope curve" vs. the trend pressure. As blood pressure values are usually rounded to 5 mmHg we find a blood pressure of 120/80. A best-fit bell-shape envelope is drawn in the graph to find the maximum (MAP).*

Method 2 – via derivative graph

14. Right-click the *p-difference* vs. *p-trend* graph and select *Analyze/Process > Derivative.*
15. Select under Run the option *Run 5*.
16. Select under Variable the variable *Fit of p_difference5*
17. Select under Order *First derivative* and under Method *Differences*.
18. Click *Plot*.
19. Accept with OK.
20. Click a pane to place the Derivative graph.
21. Use the *Scan* function to read out the blood pressure values.
    - The pressure value of the intersection of the derivative with the horizontal axis corresponds to the MAP value.
    - The pressure value of the minimum of the derivative graph corresponds to the systolic pressure.
    - The pressure value of the maximum of the derivative graph corresponds to the diastolic pressure.

Reference values

The table below indicates normal heart frequency and blood pressure values for boys and girls for ages between 10-19 years old.

Age	Heart frequency per minute		Systolic pressure average ± SD		Diastolic pressure average ± SD	
	boys	girls	boys	girls	boys	girls
10 jr	132	129	108±12	109±13	67± 9	64±11
11 jr	160	131	109±11	110±12	65±11	66±10
12 jr	150	147	111±13	114±14	65±10	68±10
13 jr	144	141	116±14	116±14	66±11	68±10
14 jr	127	143	118±14	116±12	66±10	69± 8
15 jr	128	127	123±14	116±11	66±11	68±11
16 jr	106	135	125±14	118±12	68±11	69± 9
17 jr	107	115	126±13	121±13	70±11	70±10
18 jr	85	85	129±15	122±14	71± 9	71±11
19 jr	94	77	131±15	120±12	71±10	70±10

Table 1: From: van den Brande, Heymans & Monnens, *Kindergeneeskunde*, Elsevier

Suggested experiments

The following experiments can be performed with the Blood Pressure sensor:

- Using the oscillometric method to calculate blood pressure.
- Measure blood pressure before and after exercise and while sitting or standing.
- Compare blood pressure after voluntary isometric contractions (weight lifting) and a rhythmic activity such as running or biking.
- Study the effect of caffeine on blood pressure.

Technical Specifications

Sensor kind	Analog, generates an output voltage between 0 and 5 V
Measurement range	0 .. 375 mmHg
Resolution	0.1 mmHg
Calibration function	p (mm Hg) = 83.34 * V_{out}(V) – 16.67
Max. pressure	1500 mm Hg
Temperature compensated	-0°C to 85°C
Response time	1 ms
Warming time	20 ms
Connection	IEEE1394 connector for BT-IEEE1394 sensor cable. Sensor cable not delivered with the sensor.

Warranty:

The Blood Pressure sensor BT17i is warranted to be free from defects in materials and workmanship for a period of 12 months from the date of purchase provided that it has been used under normal laboratory conditions. This warranty does not apply if the sensor has been damaged by accident or misuse.

Note: *This product is to be used for educational purposes only. It is not appropriate for industrial, medical, research, or commercial applications.*

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