Modelling Emission of Climate gases

Using mobile sensing data

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Contents

1 Introduction

During the last 40 years an overwhelming amount of evidence for Anthropogenic Global Warming has been gathered [9]. This evidence has led to international agreement on certain limits for the emission of gases that affect the global warming, most notably CO2. In order to reach these goals and keep the level of CO2 within the agreed limits, technological solutions need to be developed, partly to develop cleaner energy production technology, and partly to develop more energy efficient ways of living. Previously the focus has been on developing more efficient machines, under the assumption that the use patterns of the energy consuming machines were optimal.

The research project EcoSense is aimed at analysing user behaviours, and if possible give advice to change user behaviour to be more resource efficient.

One driving goal for the project, is to be able to improve the accuracy and ease of use of green accounting for companies. Today it is a tedious and time-consuming task to estimate the amount of emissions a company is responsible for. One of the cumbersome areas of green accounting is with regard to emissions due to transport. There is a need for methods and models that will account for the actual emissions due to the day to day business of the company and not accounting done from mean values.

My contribution to the project is threefold: 1) to create and improve emission models for individual trips. 2) to create models for aggregation and correlations of multiple trips. 3) to improve models for the dispersion of emissions.

By succeeding in these goals the impact would be: Improved accuracy of green accounting Providing hints to increase efficiency of transportation

[More on EcoSense motivation Reading guide]

2 Climate change policy development

2.1 Climate change organisations

2.2 Climate change mitigation

From the start of the debate about how to combat Anthropogenic Global Warming, there have been two competing approaches. The mitigation approach, where an effort is made for reducing the emissions of climate gases, is the approach which has received the most attention. The EcoSense 3 project is part of the mindset behind this approach. Whereas the mitigation approach previously has focused on creating more efficient machines, to either produce energy with less emissions or produce machines that produce more useful work per energy unit, EcoSense focuses on how the machines are used in combination. So instead of focusing on a single energy consuming item, we are trying to analyze how the energy consumption reacts as the individual items work together. In other words we are developing tools for studying networks effects in the transportation sector, as well as in other sectors.

2.3 Climate change adaptation

The second approach is called the Adaptation approach. Since it is probable that there will be significant changes in the climate, even if we succeed in keeping the CO2 emissions within the agreed limits, we have to invent ways to adapt to these changes. The Adaptation approach has not received much attention or research funding, but projects like EcoSense will also have an impact in determining how to adapt to changes in weather patterns. It seems that IPCC in the 5. report from Working Group 2 is beginning to give more attention the the Adaptation approach, as a consequence of realizing that some level of Climate Change is inevitable.

3 CO_2 Modelling

3.1 Simple emission model

A simple model for estimating the emissions from single trips has been developed. The trips are divided into sections by the transportation mode detection algorithm. For each transportation mode a emission factor is calculated and multiplied with the length of the section. The total emission for a trip is calculated by accumulating the emissions from the sections. The emission factors for cars, trucks, busses and trains are derived from the reporting of the national emission inventories to UNFCC under the Kyoto Protocol.

3.2 IPCC methodology

The scientific panel guiding the political decisions made in UNFCC is called IPCC (Intergovernmental Panel for Climate Change). The IPCC has made a number of reports on how to calculate emissions of climate forcing gasses and pollutants. The gasses that IPCC are describing methods for are divided into four groups:

Group 1 are pollutants where a detailed methodology for estimating the emission from activity data, such as driving conditions, and engine conditions.

Carbon monoxide	CO
Nitrogen oxides	(NOx: NO and NO2)
Volatile organic compounds	(VOCs)
Methane	(CH4)
Non-methane VOCs	(NMVOCs)
Nitrous oxide	(N2O)
Ammonia	(NH3)
Particulate matter	(PM)

Table 1: Group 1 species

Group 2 are pollutants which can be estimated from fuel consumption, when there is a direct connection between the burning of fuel and the emission. In this group the pollutants are: The data for the Group 2 pollutants are regarded as precise as the data for the Group 1 pollutants even if the methodology differs. Group 3 and Group for pollutants are organic compounds, where no detailed methodology exist for estimating the emission, so simple method is used to calculate the emission.

The fourth group of pollutants are species, where the emission is calculated as a fraction of the Non Methane Volatile Organic Compound (NMVOC).

Carbon dioxide	(CO_2)
Sulphur dioxide	(SO_2)
Lead	(Pb)
Arsenic	(As)
Cadmium	(Cd)
Chromium	(Cr)
Copper	(Cu)
Mercury	(Hg)
Nickel	(Ni)
Selenium	(Se)
Zinc	(Zn)

Table 2: Group 2 species

Polycyclic aromatic hydrocarbons	(PAHs)
Persistent organic pollutants	(POPs)
Polychlorinated dibenzo dioxins	(PCCDs)
Polychlorinated dibenzo furans	(PCDFs)

Table 3: Group 3 species

Alkanes	(C_nH_{2n+2})
Alkenes	(C_nH_{2n})
Alkynes	(C_nH_{2n-2})
Aldehydes	$(C_nH_{2n}O)$
Ketones	$(C_nH_{2n}O)$
Cycloalkanes	(C_nH_{2n})
Aromatic compounds	-

Table 4: Group 4 species

When considering Climate forcing gases the most important gasses are in Group 1 and 2, thus this is what the focus has been on in this phd study.

The way emission inventories are created are described in the the Guidelines from IPCC . In the guidelines three different methods ere described, each method more accurate than the previous.

3.2.1 IPCC Tier 1 model

[Size of data (small)]

The Tier 1 method are based on numbers for national sales of hydrocarbons (Gasoline, Diesel, Natural gas etc.). These numbers are readily available for most countries and are converted into emission inventories by multiplying emissions factors (grams of the specie pr kilogram of fuel) for each type of fuel. The Tier 1 method is the simplest, but also most crude way of estimating the national emissions.

Formulas

3.2.2 IPCC Tier 2 model

[Size of data (large)] In the Tier 2 method the emission inventories are estimated by estimating the traffic volumes for different categories of vehicles, and multiplying emission factors (gram pr kilometre) for each category. The vehicles are divided into 6 main categories: Passenger Car, Light Duty vehicles, Heavy Duty vehicles, Buses, Mopeds and Motorcycles. For each of the main categories, a subdivision is made, to accommodate for different emission characteristics stemming from pollution regulation, fuel type and engine size. For instance, in Europe, passenger gasoline cars are subdivided into 13 different types, according to the legislation governing allowed emissions. These regulations has been changed and tightened 13 times since the first emission control legislation was ratified in the early nineties. For each vehicle category and vehicle type and legislation class, activity data has to be obtained. The activity data consist of the number of vehicles, and the number of kilometres they drive pr year, for each class. The IPCC has generated tables of emission factors (as g/km) for each class of vehicles. By multiplying these emission factors with the estimated kilometres and number of vehicles in the class, the total emission of a pollutant can be estimated for the vehicle class. The total annual emission from transport can then be calculated as the sum of all the vehicle classes.

Formulas

3.2.3 IPCC Tier 3 model

[Size of data (huge)] The Tier 3 method takes the Tier 2 methods and improve on the estimated emission, by also consider the velocity distribution of the travelled distances, and by considering the effects of cold-starts on the total emissions.

There are two ways proposed to calculate the effects of speed on exhaust emissions. Either by dividing the travelled distance into road types with different speed characteristics, i.e. urban, rural and highway. In this case the total emission for a vehicle class will be calculated as the sum of the product of travelled distance on a road type and the emission factor for that road type and vehicle type.

The other method uses a measured speed to emission curve and a speed distribution function to estimate the emission. The emission is calculated as the integral of the speed distribution multiplied by the emission function.

MORE formulas

$$e_{i,k,r} = \int e(V) * f_{k,r}(V) dv \tag{1}$$

(i is the the pollutant for which the emission is calculated).

3.3 Modelling emissions from electric vehicles

The emissions for electric cars are calculated from near real time emission data from Energinet.dk, under the assumption that electric cars will be charged with electricity from the public grid. There is for now no way to detect if the charging of electric vehicles are not done through the public electric grid.

3.4 Implementation

The emission factors for combustion engines, as used in the national emission inventories, are based on measured emissions from standardised test runs, and are used for a bottom up estimate of the total national emissions, by estimating the number of kilometres the total national fleet have driven. This estimate is compared to an estimated emission calculated from the amount of gasoline and diesel sold nationally, and the difference between these two estimates leads to a correction factor for the total national emission.

The emission factors are estimated for 3 different driving patterns: Urban, with many stops and low speed. Road driving, with few stops and moderate speeds, and lastly highway, with no stops and high speed. These three modes of road traffic can be distinguished by analysing GPS. The GPS datapoint contains data for timestamp, Latitude, Longitude, speed and accuracy.

To create a more accurate estimate of the emission for a single trip by car, a more complex model is proposed. From the sensed data it is possible to get

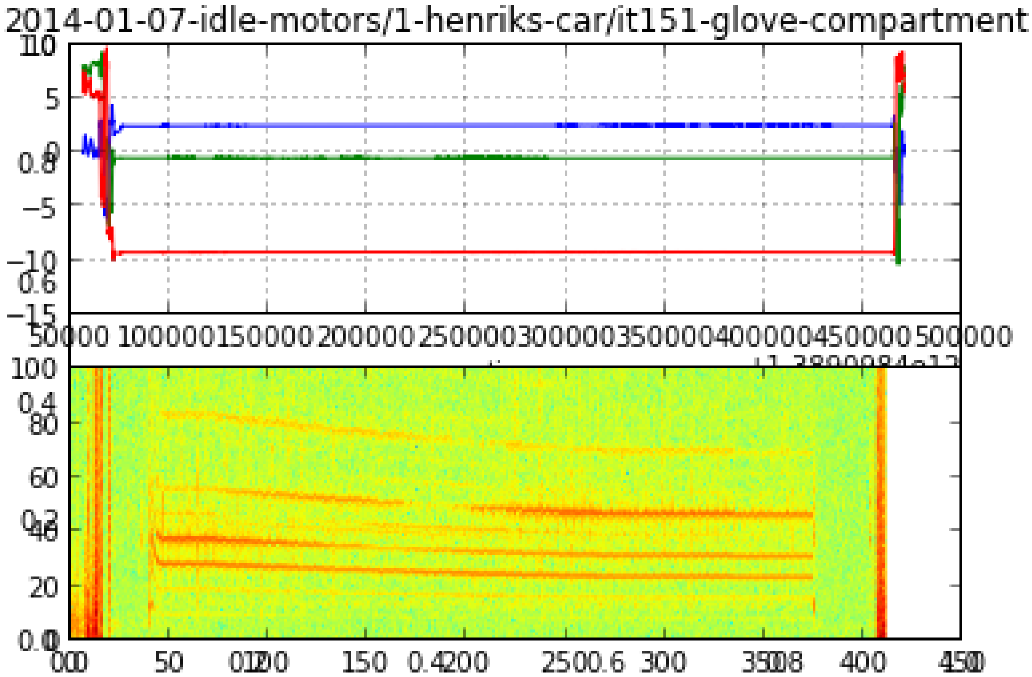

Figure 1: **default**

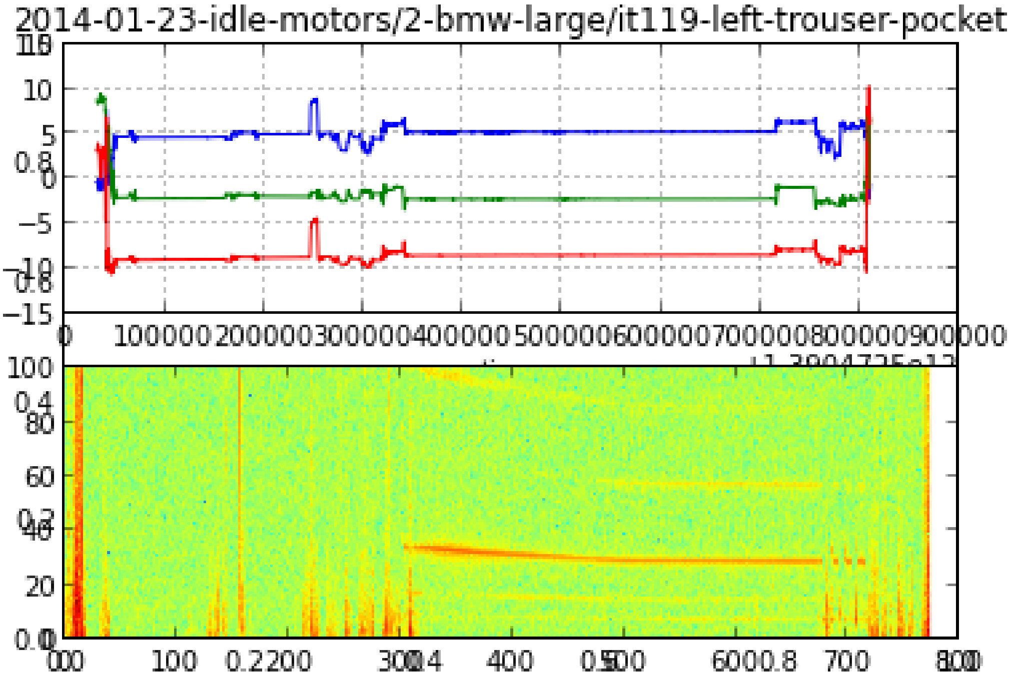

Figure 2: **default**

information on the speed of the car at various points of the trip, and the number of stops and starts. This information can be used to further segment the trips into idle, accelerating, cruising and braking; each of these segments would have a different emission profile.

The data sensed from the smartphone can also be used to determine if the engine in the car is cold, if for instance it is the start of the trip. When the engine is cold the combustion is less effective and thus more emissions of Carbon Monoxide and Volatile Organic Compounds will be higher and the emission inventory should reflect that. The determination of the impact of cold starts, demands quite complex models, taking into account the temperature, models for engine warm up.

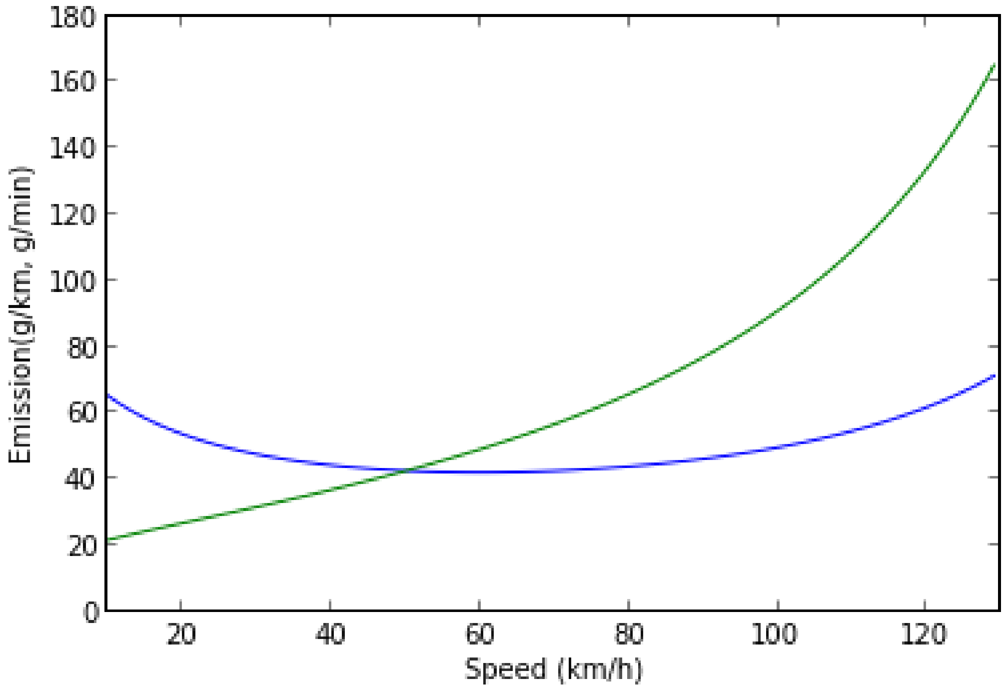

Figure 3: **default**

3.4.1 Determine engine revolutions

By analysing the frequency spectrum of the accelerometer data, information on the engine revolutions can be retrieved. By employing spectrograms (shows the time evolution of spectral features) changes in engine speed can be visualised. An example is the the idle speed of a cold motor, where the ECU (Electronic Control Unit) of the vehicle, measures the temperature of the motor and as long as the motor is too cold, sets the idle speed at a higher value. The lowering of the idle speed as the engine grows warmer, is clearly visible in the spectrogram. The spectrogram is calculated by calculating the size of the accelerometer vector, i.e.:

$$a = \sqrt{x^2 + y^2 + z^2}$$

By calculating the size of the accelerometer vector we do not need to know the exact orientation of the smartphone, and since the gravity can be consider constant the gravity will be present as a signal with frequency equal to zero, which can easily be removed. The spectrogram shows the time evolution of the frequency spectrum of a signal, so the y-axis shows the frequencies, and the x-axis shows the time. The size of individual frequencies is shown by using different colours. The usefulness of the spectrogram is to show signals with few frequencies that change slowly, and not to ascertain the exact sir of individual frequencies. The spectrogram can therefore be said to be a qualitative display technique.

During driving, the vibrations from of the moving car, that is the vibrations of from the tires moving over the road and vibrations from the transmission system, drowns the signal of the engine rotational speed.

Another effect that contributes to the loss of a clear signal for the rotational speed of the engine is due to the low sampling frequency of the accelerometer. The sampling frequency of the accelerometer i approximately 200 Hz. This means that the data from the accelerometer only can represent signals with frequency below 100 Hz, due to the Nyquist criteria. This maximum frequency of 100 Hz corresponds to a engine speed of 6000 rpm. Thus the sampling frequency only allows for accurately representation of frequencies below 6000 rpm, and if higher vibrational frequencies exists these frequencies will be folded back into the spectrum from 0 to 6000 rpm, a process called aliasing. Since combustion engines often employ more than one cylinder, and since the process of combustion takes place as a violent process in the cylinder, it is reasonable to expect harmonics of the engine speed to be created. When the engine is in idle mode a rotation of 900 - 1000 rpm is normal and the sampling of the accelerometer will allow the correctly represent up to the 6th harmonic, but when the vehicle is driving engine rotation speed between 2000 - 3000 would be appropriate, thus only allow to represent third or only second harmonics. Any higher order harmonics will be aliased back into the spectrum and contribute to the noisy picture.

As a result of vibrational noise from the moving vehicle and aliasing of engine vibration (and aliasing of the vibrational noise for that matter) the signal from the engine rotation is lost in the noise. In signal analysis, the way to prevent aliasing is to apply a low pass filter to remove or dampen frequencies above half the Nyquist frequency. But in our application it is not possible to ensure that the smartphone containing the accelerometer is adequately shielded from high frequency vibrations.

3.4.2 Determine acceleration and turning

I order to distinguish between the the four modes of driving (idling,accelerating,cruising, decelerating), which have different emission characteristics, we can use the accelerometer data to determine the the acceleration patterns in the horizontal plane. The data from the accelerometer is 3 values for each measurement, which are the 3 axis from the accelerometer. The direction of movement of the phone can be determined by analysing these 3 signals. First the direction of gravity is determined. Since it is possible for the phone to be moved freely in all directions and/or flipped with the movement of the person wearing the phone, the gravity detection needs to be dynamic. When the direction of gravity has been determined, it is possible to detect acceleration in the horizontal plane. This allows us to consider distinguishing turning from linear acceleration.

3.4.3 Combine turning information with GPS

By combining the turning information, with GPS localisation and map data, the accuracy of the positioning of the car can be improved. Improving the positioning accuracy is important for improving the accuracy of the calculation of trip length and segment of trips length.

The more accurate trip emission estimate would be of interest for instance green accounting purposes.

To validate and compare the models the exact emissions can be measure by inserting a sensor into the exhaust pipe of the vehicle under test. By doing test runs in different kinds of traffic, and with different vehicles the results of the sensor can be compared with the results of the models.

4 Air pollution dispersion Modelling

5 Internet of Things

The vision of Internet of Things is to connect devices, across application, geographic and company boundaries. To accomplish this vision, a common language and framework had to be agreed upon. Tim Berners-Lee started this work by creating the Resource Description framework (RDF) in ????. The definition of have spurred the creation of query languages (SPARQL), semantic frameworks (OWL, SKOS), IDE (Protégé, TopBraid composer) and implementations (SESAME, Virtuoso, Talis, RDFLIB).

5.1 Linked Data

5.2 Semantic annotated data

5.3 Linked Devices

5.4 Linked Data as an Enterprise Architecture strategy

6 Future Research

In this section the planned work for the remainder of the phd study will be discussed. The focus of the section is the planned scientific contributions.

6.1 Improving estimation of emissions for single trips

As outlined in section 3.1, the current modelling focus is to create and maintain national inventories, which leads to a focus on mean values for emission factors, driving patterns and trip patterns. To be able to provide personalised information on specific transportation behaviour, there is a need to provide more detailed models for the emission of single trips. In this section an outline for possible algorithms for reaching that goal is presented.

One proposal is to divide a trip into four different types of driving : Idle, accelerate, cruise and decelerate. For each type of driving a emission profile can be derived and thus the emission for each type can be determined. To total emission for a trip can then be determined as the sum of the emission for each type.

6.1.1 Idle emissions

Detection of idle situations can be done with combination of GPS data and accelerometer data. The GPS data can be used to estimate the speed of the vehicle, and the accelerometer can be used to measure the engine speed to confirm that we are in idle mode. There are some literature about measuring emissions from idling, but it might be necessary to update with new measurements. A possible source for idle emission data could be the approval data for Danish biannual vehicle inspections, since part of the inspection is a measurement of the contents of the exhaust in idle mode.

6.1.2 Emissions when accelerating

The horizontal acceleration can be determined by finding the direction of gravity in respect to the device, through a variety of methods. These methods will have to be evaluated to find a suitable solution for the application at hand. When the gravity direction has been determined, the horizontal acceleration will be either close to zero, when cruising or idle, or have a significant value due to acceleration, turning or deceleration. It is believed that it will be possible to provide a stable algorithm for detecting horizontal acceleration and distinguish between turning and acceleration.

To model the emission from an accelerating vehicle information, such as engine size and vehicle weight, is needed. This information has to be given as input to the model by the user, or be inferred from the Transportation Mode Detection part of EcoSense.

Another input to the model could be the road grade, since the engine will have to work harder, thus emitting more pollutants, if the vehicle is going uphill. By using the GPS data to get information on the position, the road grade can be gleaned from a digital road network. By fusing the information from these different sources the emission modelling can be further improved.

6.1.3 Emissions when decelerating

When decelerating, there are a couple of different situations to be ware of. The simplest situation is when the vehicle is braking using the mechanical brake. In this situation the engine will typically be in idle mode and the results from section 6.1.1 can be reused. If the vehicle incorporate regenerative braking, motor braking or automatic transmission the situation is more complex. The proposal is to first ascertain if deceleration can be detected and then in an first approximation used the results from 6.1.1

6.1.4 Emissions when cruising

In the study of emission models, models for speed dependency of emissions have been found. These models can be used as is if we can determine that we are moving at a constant speed. These models are described in section 3.1. The models are developed for emission modelling programs such as COPERT IV, which was developed as part of the EU project ARTEMIS. The models used in COPERT IV can be used to assign a speed dependent emission factor to specific vehicle types, engine sizes and fuel types.

6.1.5 Papers

Paper 1

6.2 Correlation of trips

In order to be able to spot inefficiencies in transportation patterns, a way of group, aggregate and correlate different trips are needed. The grouping of trips could be by persons, time of day, seasonal or geographic. The aggregation could be looking for all trips at specific location in a certain time period. Correlation is useful for finding trips which follow a certain route.

In order to solve these problems efficiently, some heuristics may be useful. If a digital road network is available for the area under consideration, each trip can be converted into a subgraph of the digital road network, under the assumption that vehicles travels along the roads. By having the trips as a graph instead of a time series of GPS locations, will simplify the task of correlation, thus good and efficient algorithms to convert GPS traces to road network graphs is needed.

6.2.1 Impact

6.2.2 Papers

6.3 Field trials

Among the partners in the EcoSense project are some municipalities. The interest from the municipalities in the EcoSense project are among other, to be test sites for the results coming out of the project. In return the researcher partners get real world data to learn from in future research

6.3.1 Sønderborg

6.3.2 Herning

In Herning a project called "Herning cycler til månen", Herning bikes to the moon. The goal of the project is to get the citizens of the municipality to bike the distance to the moon. To measure the distance travelled on bike, participants can download an mobile application, developed in the EcoSense project. The app sends data to the EcoSense servers, and we thus get the possibility to look into real world transportation.

6.3.3 Papers

6.4 Visiting researcher

7 Conclusion

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